The Dynamic Futures for NRC Mission Areas

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

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Executive Summary

After exploring how the external environment in which the NRC operates might evolve through 2030 and beyond, it is apparent that the potential nuclear futures are varied and dynamic. Shifting demand patterns, the global evolution of reactor designs and digital technologies, new approaches to decommissioning and nuclear waste, diverse uses for nuclear materials, and the evolving nuclear workforce will all be key contributors to change.

Using a scenario planning methodology, this report explores how the NRC's external operational environment might evolve through 2030 and beyond as well as the potential impact on the NRC's future mission delivery, operations, and people. Key trends and critical uncertainties were developed through a series of interviews and research to enable this analysis. These served as the basis for a workshop with NRC personnel to create four possible future scenarios in which the NRC might operate in the years 2030 and beyond. The four scenarios were built on two foundational axes, U.S. nuclear power demand and the level of innovation in nuclear reactors globally, to explore hypothetical futures.

Exploration of the hypothetical futures produced several key takeaways for agile NRC responses to evolving mission needs. The NRC perceives this as an opportunity to truly transform to meet the challenges of a changing industry, to improve delivery on current and future missions, and to prepare its workforce for 2030 and beyond. Anticipation and preparation for the future places the NRC in a far better position to thrive regardless of whatever future emerges.

The key takeaways in this report include the following:

- The ***future external environment*** in which the NRC will operate in 2030 and beyond is ***uncertain***, with wide variations in possibility in the number of reactors in the United States, the level of technological advancement of those reactors, the use of nuclear materials, and the management of nuclear waste, among others. However, it is ***far from entirely random***. Monitoring and preparing for how the future will unfold can allow the NRC to be ***more agile and resilient*** to the range of possible futures;
- ***Increased agility*** (i.e., the ability to act quickly and easily) is needed to ***support changing demands and anticipated innovation*** in nuclear technologies and reactor design;
- An increasingly ***adaptive strategy including risk-informed and performance-based approaches*** to regulatory oversight, ***governance*** that accommodates the anticipated rate of change, and a ***culture*** that is more flexible going forward are needed to ***support a dynamic, uncertain future*** with rapid and potentially non-linear evolution of the nuclear industry and related technologies;
- In shifting from an aging workforce to a younger generation, ***attracting, developing, and retaining the right talent and knowledge*** is critical to meeting the NRC's evolving mission, though what constitutes the "right" talent will vary depending on how the future unfolds;
- ***Data analytics, cognitive technologies*** like artificial intelligence and robotic process automation, and knowledge of ***technologies that reduce the need for physical presence*** such as remote sensing/monitoring can enable the NRC to be ***more efficient***;
- ***Stakeholder engagement and transparency*** will remain ***a principal element*** as the NRC interacts with a more diverse set of stakeholders using evolving communication platforms.

These takeaways are by no means exhaustive, and as the NRC progresses towards a dynamic nuclear future, new factors could emerge that could affect how the NRC needs to accomplish its mission. The challenge will be to align the NRC's resources and process to regulate licensees in a competitive energy market and nuclear industry, in whichever futures emerge, in a manner that is timely, elevating, and does not stifle innovation. This will entail continuing to work closely with diverse stakeholders in both private and public sectors.

This report does not provide predictions or forecasts of the most likely futures, but hypotheses about potential futures, in order to help the NRC to evaluate and plan for how the NRC will need to effectively deliver on its mission in the future. It represents the combined inputs from a wide variety of stakeholders both internal and external to the NRC. By preparing for the dynamic ways the future might unfold, the NRC can continue to evolve regulatory approaches that are practical in a dynamic nuclear future that will ensure reasonable assurance of public health and safety, promote common defense and security, and protect the environment.

Letter from the Executive Director for Operations

The NRC is preparing for an evolving future that will include new and different opportunities. This is an exciting chance to shape our workforce and enhance the technology, skills, and other tools we need to continue to accomplish our important safety and security mission.

While the NRC has been successful in planning for near-term changes in its environment, the dynamic changes envisioned in the future across all mission areas require a more anticipatory and longer-term approach to planning. We realized that looking further into the future would require a creative, scenario-based review, and I am pleased to share this report with you. This report is the first step towards an effort we call the "Futures Assessment."

In October 2018, the NRC set in motion the Futures Assessment effort as a way of ensuring that the NRC continues to effectively meet its mission in the future (i.e., 2030 and beyond). The goal of the Futures Assessment effort is to understand the various ways the future of the NRC's external environment could change, how the NRC could be affected, and steps that the NRC could take to be prepared for those changes. This report describes four scenarios that describe potential external environments in which the NRC could operate in the future, as well as potential impacts from those environments.

As we embark on our next step of evaluating the report and identifying approaches for the future, we will continue to promote transparency with the public and our stakeholders as the future drives planning changes (e.g., for applications and other reviews). At the same time, we will strengthen our relationship with international partners, building from their efforts and advancements. Within our organization, we will begin to shape the workforce of the future. I am confident that the Futures Assessment effort will inform our existing planning activities.

It is imperative that the NRC evolve along with its environment. I will continue to encourage the employees of the NRC to be open to new and creative ways of achieving our mission. While stretching our thinking in this manner may feel uncomfortable at times, such innovation and adaptation will ensure that the NRC will proactively respond to its evolving external environment.

This report is informed by insights derived from NRC employees, as well as external stakeholders. We will use the insights in the report to evaluate how we should change to prepare for the future. The result will be an NRC of the future that achieves its safety and security mission, while remaining a great place to work.

I thank everyone who contributed to this report, and look forward to working with you on this journey to the future.

Sincerely,

Margaret M. Doane
Executive Director for Operations
U.S. Nuclear Regulatory Commission

Key Terms and Acronyms

Advanced Reactor	Non-light Water Reactor
AI	Artificial Intelligence
Agreement States	States that have entered into agreements with the NRC to regulate byproduct, sources, and limited quantities of special nuclear materials used or owned.
ASLB	Atomic Safety and Licensing Board
CISF	Consolidated Interim Storage Facility
Critical uncertainty	A driving force with the potential to move the future in multiple directions, but where the direction is highly uncertain
Digital I&C	Digital Instrumentation and Controls
DOE	Department of Energy
Driving force	A driving force is a fundamental source of future change that can shape the course of events and history. It can be a key trend where the direction of the force is known or a critical uncertainty (as defined above)
EDO	NRC Office of the Executive Director for Operations
FDA	U.S. Food and Drug Administration
IAEA	International Atomic Energy Agency
IT/IM	Information Technology/Information Management
HQ	Headquarters
LLWR	Large Light Water Reactors
LWR	Light Water Reactors
Marker	Trail markers that hint at which signpost, and ultimately which future, you might be moving toward
NRC	Nuclear Regulatory Commission
R&D	Research and Development
RPA	Robotic Process Automation
Scenario	A rich, data-driven narrative description of the external environment in which an organization may need to operate in future
Signpost	Precursor towards the direction of the future. Reflects the broader conditions in the environment being monitored
SMRs	Small Modular Reactors

Foreword

This report's key objective is to change the NRC's collective mindset and explore what the future, external nuclear environment might be, so we can begin to best prepare for a range of possibilities. This effort builds on other recent NRC initiatives that have explored the organization's current-state and aspirational goals (e.g., Project AIM, etc.), to establish a scenario-based outlook of our evolving environment.

We have presented four possible nuclear futures as narratives, defined by two factors chosen for their transformative potential and pertinence to the discussion: (1) U.S. nuclear power demand (from low to high); and (2) Global reactor innovation (from incremental only to disruptive and incremental). These narratives provide aspirational and cautionary nuclear industry outcomes, which are used to derive a series of observations and insights on market, technology, and policy factors to identify potential actions and options for optimizing regulatory efforts in a dynamic future.

This paper does not offer policy recommendations or provide strategies that would enable one future narrative over the other. It does not set target expectations for specific reactor types or radioactive material usage, but rather observes a range of factors that, ultimately, could shape each future narrative and determine the impacts on areas of the NRC's mission. We recognize that other factors may emerge in the future that could have a significant mission impact. Thus, it is incumbent on all of us to be accountable in embracing our role to increase flexibility and use this document along with prior initiatives as guides to inform our ongoing planning and execution in enabling the NRC's mission regardless of the future ahead.

Introduction and Approach

The United States Congress created the Nuclear Regulatory Commission (NRC) as an independent agency in 1974 to ensure the safe use of radioactive materials for productive civilian purposes while protecting people and the environment. The NRC regulates commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine, through licensing, inspection, and enforcement of its requirements. The NRC is not an advocate of nuclear power or uses of nuclear materials and does not set energy policy. However, it is the regulatory agency responsible for licensing and oversight of nuclear and radioactive material, including nuclear power.

Today, the NRC's regulatory activities are focused on safety oversight of the largest fleet of operating reactors in the world and license renewal of existing reactor license, materials safety oversight and materials licensing for a variety of purposes, waste management of both high-level waste and low-level waste, and confirmatory research to support regulatory decisions. In addition, the NRC evaluates applications for new designs of nuclear power plants.

There are a number of potential futures for the external environment in which the NRC will operate. The future will be shaped by evolutionary and disruptive developments not just within the nuclear industry, but also the electric power industry. Already, the disruptions caused by flattening of bulk power demand, low natural gas prices, and the growth of renewable power generation technology have placed substantial pressure on the existing nuclear power fleet and slowed down the construction of new nuclear power generation. The potential of advanced nuclear reactor designs and the potential of new market players entering the decommissioning and nuclear materials industries could further alter that external environment. In addition, developments in the broader environment – such as changes in the demand for energy if electric vehicles become the predominant vehicle type or changes in the U.S. workforce as millennials start to rise to positions of senior management – will have an impact on the NRC's regulatory activities and on the way the NRC carries out those activities. The futures the NRC will face are therefore complex, fast moving, and uncertain – or in a word, dynamic.

This report explores how the NRC's external operational environment might evolve through 2030 and beyond as well as the potential impact on the NRC's future mission delivery, operations, and people. From the NRC's perspective, there will be challenges and opportunities associated with any of the futures. One thing is certain: anticipation and preparation for the future will put the NRC in a better position to capture benefits and address the potential downsides from whatever future emerges.

The Scenario Planning Methodology

The NRC has chosen a scenario planning methodology to explore the range of potential futures. Many players within the energy industry, including Shell and the Department of Energy (DOE), use this approach. Scenario planning is a methodology that creates detailed, data-driven stories about potential futures that can drive better decisions today. Scenario planning as a methodology recognizes that the future holds a truly extraordinary range of possibilities, and no single view of the future can contain them all. Indeed, many of the future possibilities are directly contradictory. The scenario planning approach creates a set of scenarios that cover the fullest possible range of uncertainty. By embracing uncertainty, and combining rigor with intuition, scenarios trigger insights into the trends and dynamics driving change. They can reliably generate insights, create clarity, enable commitment, and inspire action.

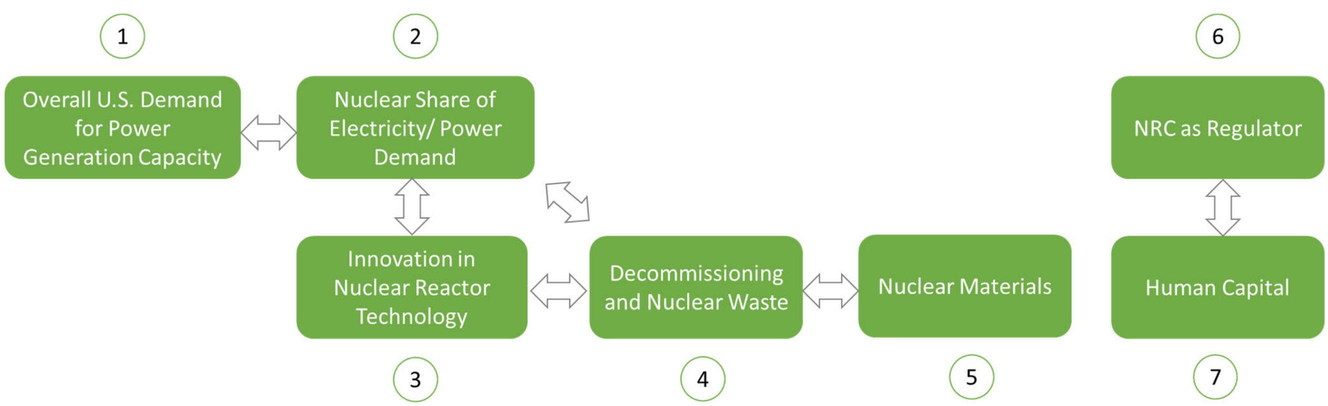
The result of applying the scenario planning methodology in the creation of this report was the set of four scenario stories – developed with internal and external input – that are captured in the Nuclear Narratives section of this document. These scenario stories describe the external environment of 2030 in which the NRC may need to operate, to create a framework for recognizing and adapting to change over time, ahead of time. They are deliberately written as narratives with a coherency and a logic that interweaves issues, to better immerse the reader in the world of 2030. Adding the powerful element of a narrative makes the scenarios easier to remember, and has the power to engage and inspire that a list of issues cannot match. Each scenario was also given a short, memorable title to serve as a mnemonic for the wide variety of conditions in the external environment encapsulated within the scenario and to stimulate discussion. Together, the four scenarios are a means to help the NRC structure how it considers the crucial strategic choices and contingencies it may need to make today and in the near term to be resilient and flexible for what the future may hold.

It is important to remember that scenarios, while always grounded in plausible assumptions and logic, are meant to be narratives that stretch an organization's thinking. Their intent is to expand an organization's mindset beyond what the conventional wisdom of the day holds as the expected future. They are thus not predictions or forecasts of the most likely futures, but hypotheses about potential futures that allow organizations to develop and test their strategic choices under a wide variety of plausible futures.

Driving Forces in the NRC Operating Environment

The first step in developing the scenarios was research and interviews with internal NRC senior leaders and staff, and external stakeholders and experts. (The Acknowledgements section contains a list of internal and external stakeholders engaged through this process). The primary objective was to understand and map the key driving forces that will shape the NRC's external environment of 2030. By driving force we refer to a fundamental source of future change. It can be a trend in a given direction, or a critical uncertainty where the direction is highly uncertain. Seven driving forces were identified, as illustrated in Figure 1 and detailed below:

Figure 1: Categories of Identified Driving Forces



1. *Driving forces in the overall U.S. demand for power generation capacity.* This includes trends and uncertainties around the overall size of the U.S. economy; whether increased use of electric vehicles, desalination, or other new energy-intensive industrial processes could cause demand for power generation to grow exponentially, and conversely whether there are any major disruptions in energy efficiency or consumption that would shrink demand.

2. *Driving forces in nuclear's share of electricity and power demand in the United States.* This includes trends and uncertainties in the affordability of nuclear energy compared to other sources such as natural gas and renewable energy; the feasibility and reliability of large-scale deployment of renewable energy; the role of nuclear power in energy, environment, and climate policies; and public acceptance of nuclear energy, including of the safety and security of nuclear power.
3. *Driving forces in innovation in nuclear reactor technology globally*. This includes trends and uncertainties in nuclear reactor design, such as whether Generation IV / advanced non-light water reactors are deployed widely; in nuclear reactor sizes, such as whether small modular reactors (SMRs) and micro-reactors see widespread deployment; in reactor construction, including speed and the use of innovative new materials; and reactor operations, including the deployment of digital instrumentation and controls (I&C).
4. *Driving forces in decommissioning and nuclear waste.* This includes trends and uncertainties in the quantity of low-level and high-level waste being produced; whether storage facilities including consolidated interim storage facilities and a deep geological disposal repository are being funded; and developments in decommissioning and storage technology.
5. *Driving forces in nuclear materials and the fuel cycle.* This includes trends and uncertainties in the front end of the fuel cycle, including uranium recovery and fuel fabrication processes; in the overall demand for nuclear materials; in the use of nuclear radioisotopes for medical and industrial purposes; and where nuclear materials are produced globally.

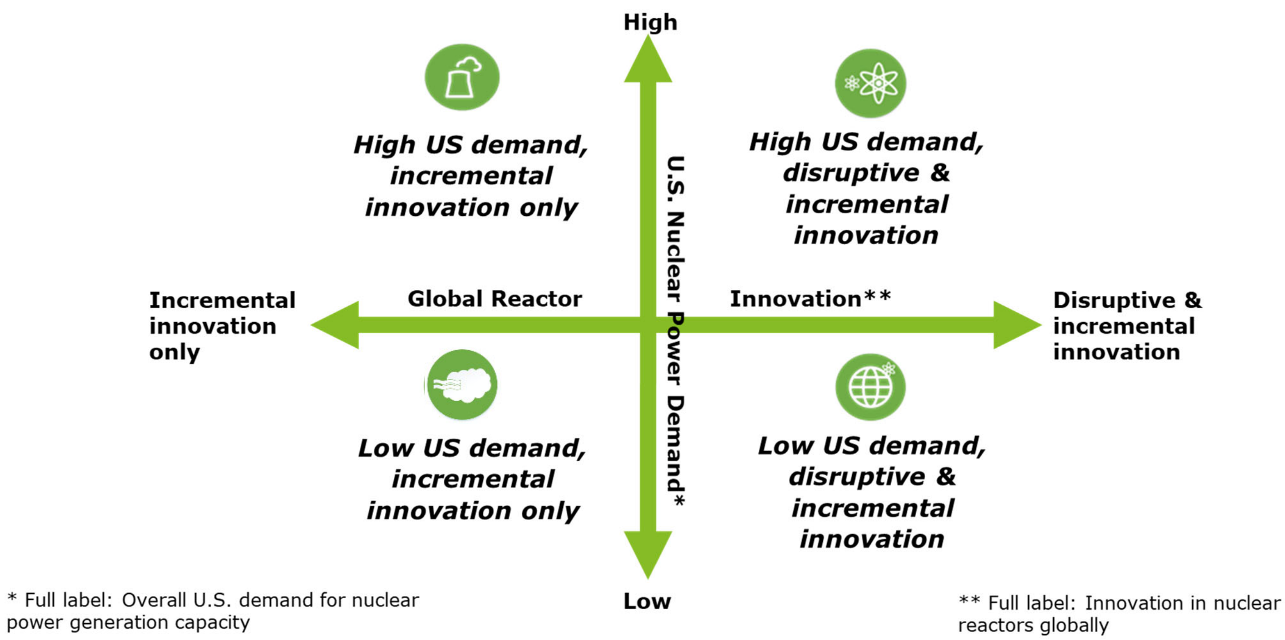
While the first five trends focused on the driving forces and uncertainties that affected what the NRC is regulating, the next two focused on the NRC as an organization.

6. *Driving forces related to the NRC as a regulator.* While the NRC will continue to operate by its Principles of Good Regulation, which ensure safety and security while appropriately balancing the interests of the NRC's stakeholders, including the public and licensees, there are trends that can affect what it means for the NRC to be open and efficient in the context of its future operating environment. Driving forces and uncertainties affecting the NRC's role as a regulator thus include whether the NRC's stakeholders in the future are changing and how the NRC can best reach out to them; whether the business models of the NRC's licensees in future will be different from its current licensees; whether there are approaches to regulation evolving across the government that could significantly enhance efficiency (e.g. use of performance-based regulation, risk-informed regulation); and whether there are available technologies that could enhance the way the NRC performs its functions. Another key uncertainty for the future was whether there could be developments that changed the expectations of the NRC's international role and activities, including the NRC's role in technical assistance for other regulators, and the need for cooperation and harmonization on international standards.
7. *Driving forces related to human capital.* This includes trends and uncertainties in the hiring environment for the NRC, such as competition for nuclear engineering talent and attractiveness of the nuclear field as a whole relative to other engineering industries; in expectations for what an NRC career looks like, particularly as generational trends suggest preferences for more frequent moving between jobs; in training approaches and delivery; and in ways to augment the workforce beyond the traditional NRC full-time staffing model, such as contracting and the use of cognitive technologies such as artificial intelligence (AI) and robotics process automation (RPA).

Scenario Development Process

These driving forces and uncertainties were then used to build out a set of four scenarios i.e. four possible futures for the external environment in which the NRC operates. To do this, a broad framework for the scenarios was developed that hinged on two main axes: the level of demand for nuclear power in the United States. and the amount of innovation in nuclear reactors globally. Research, interviews, and workshops allowed the identification of the two axes as most encompassing for the driving forces and uncertainties captured. They form the backbone of four possible scenarios of the future, as illustrated in Figure 2 below.

Figure 2: Four futures frames for the NRC



The narratives for the scenarios were then developed through a workshop process. In the first workshop, the NRC staff developed the attributes of each scenario, and supplemented that with examples of potential milestones, events, and headlines in the world of 2030 under each scenario. These were used as the basis for fleshing out the narrative threads of each scenario. The full narratives of each scenario were then refined in workshops with the NRC staff and the NRC leadership.

Nuclear Narratives

The external environment in which the NRC will operate is likely to have undergone significant changes in the future. These changes extend beyond changes in the nuclear industry that the NRC regulates to changes in other industries such as renewable energy or electric vehicles that have a second-order effect on the work of the NRC. These changes will likely be complex, but to contextualize the hypothetical and to ground the conversation, this report identifies four potential futures or scenarios that hinge on two main axes: the demand for nuclear power in the United States and the level of innovation in nuclear reactors globally.

The four futures are used throughout this report to describe market, technology, and policy factors that shape the nuclear industry and its impact on the NRC. Development of the framework and the narratives that follow leveraged staff from all levels of the NRC as well as with a wide variety of industry, environmental, and international regulatory stakeholders, as referenced in the Acknowledgements section. The four futures have titles that are simply selected to reflect the thrust of their narratives and make the scenario easy to remember. The titles are; "Nuclear Takes Off," "What's Old is New Again," "Gone with the Wind," and "Great Idea, But Not for U.S.". However, these are intended to be easy to remember labels: they are not intended to connote "good" or "bad" futures, only to stimulate discussion. The scenarios selected aim to stretch mindsets on how the NRC will face specific challenges and opportunities as it delivers on its mission.

Figure 3 summarizes the four scenarios and is followed by the full narratives for each scenario. It should also be noted that the four scenario narratives were written to capture a moment in time in 2030. However, each scenario plays out its trajectory across time. Appendix A contains descriptions of the hypothesized trajectories between the present day and the world of 2030 for each scenario.

As stated in the introduction, these narratives should be recognized as a tool to facilitate the conceptualization of the future of the nuclear industry and its impact on the NRC, rather than as concrete forecasts of the future. By structuring plausible futures within a framework, these narratives provide a systematic approach for exploring the future and generating hypotheses that expand perceptions of what may come. The actual future of the nuclear industry may include aspects of several of the nuclear narratives descriptions. For this reason, policymakers, industry leaders, and other stakeholders will need to understand the potential implications of each future state, which include distinct sets of impacts on the NRC's product lines such as operating and new reactors, nuclear materials, decommissioning, and waste.

Figure 3: Nuclear Narratives Summary

High

What's Old is New Again

Energy demand is rising as the U.S. economy continues to grow while advances in energy efficiency have plateaued. Concerns over climate change and fracking accidents have led to an increased focus on clean energy. While renewable energy is competitive, nuclear power is needed to meet the growing demand. Demand for nuclear from abroad has contributed to the growth of new designs in SMRs, but beyond modularity, nuclear reactor technology has only experienced incremental innovations. However, while these innovations are not disruptive, the improvements in construction combined with carbon taxes and government subsidies have made LLWRs more economically viable to build and operate, and existing LWR facilities are seeking to extend their productive lives. To deal with the spent fuel, two CISFs have been licensed. Although the industry is on an upswing, attracting younger workers to the nuclear industry is a challenge.

Nuclear Takes Off

Energy demand in the United States and globally is skyrocketing, in large part due to the rapid electrification of the vehicle fleet. Meanwhile, concerns over climate change have led to a renewed focus on clean energy sources. Renewable energy is cost competitive, but nuclear power is also needed to meet U.S. demand. Growing global use and supply of nuclear power has led to greater harmonization of regulations internationally. Small modular reactors are prevalent, and advanced non-light water reactor technology has improved dramatically, as has micro-reactor technology. A deep geological repository receives funding from Congress, alleviating concerns over the increased waste from increased nuclear activities. The demand for nuclear power has led to significant competition to employ and retain those with nuclear training or experience.

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U.S. Nuclear Power Demand*

Gone with the Wind

The economy continues to grow slowly, and U.S. energy demand decreases due to increased energy efficiency in use, transmission and storage, and a continued shift to less energy-intensive industries. With newer battery technology solving the intermittency problem of iteratively cheaper wind and solar generators, public opinion and U.S. policy has made a collective decision to shift toward renewables. Despite an increased environmental focus among decision makers, low-cost gas remains a major element in the energy mix while nuclear's share of electricity generation declines as the public and national leaders continue to perceive risks in nuclear energy. Hoped for breakthroughs in advanced reactor performance and nuclear plant construction costs have not materialized. New nuclear plants are being built overseas, but in the U.S., the nuclear power industry is contracting and continues to decommission non-competitive reactors. New applications and domestic producers in nuclear medicine provide the largest remaining growth opportunity for the U.S. nuclear industry.

Great Idea, But Not for U.S.

Energy demand in the United States has plateaued while globally energy demand is still soaring. Concerns over climate change have led to booming demand in renewable energy and carbon capture and storage, but a wary public does not perceive nuclear power as necessary for climate action. Reactor technology has advanced dramatically, and the U.S. continues to be in the forefront of technology development, but new plant construction is focused in the developing world. A handful of high-profile safety and security incidents at international nuclear plants has further affected the U.S. public acceptance of nuclear. The global demand for nuclear has led to a pivot of the U.S. nuclear industry away from U.S. construction toward a focus on exporting technology and expertise internationally.

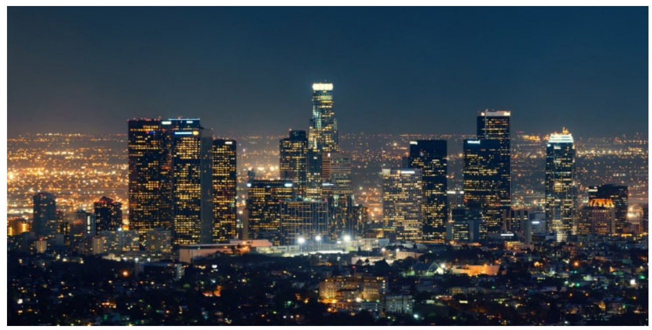
Low

Full axis labels:
** Overall U.S. demand for nuclear power generation capacity*
*** Innovation in nuclear reactors globally*

Nuclear Takes Off

November 30, 2030—Energy demand is skyrocketing in the United States and globally, in large part due to the rapid electrification of the vehicle fleet. Meanwhile, concerns over climate change have led to a renewed focus on clean energy sources. Renewable energy is cost competitive, but nuclear power is also needed to meet U.S. demand. Growing global use and supply of nuclear power has led to greater harmonization of regulations internationally. Small modular reactors are prevalent, and advanced non-light water reactor technology has improved dramatically, as has micro-reactor technology. A deep geological repository receives funding from Congress, alleviating concerns over the increased waste from increased nuclear activities. The demand for nuclear power has led to significant competition to employ and retain those with nuclear training or experience.

U.S. Energy Demand and Nuclear Share of Demand



Demand for electricity is skyrocketing in the United States and globally. In the United States, the most significant driver of demand has been the rapid electrification of the vehicle fleet; California alone now has over seven million electric vehicles on the road having reached former Governor Jerry Brown's 2030 goal of five million vehicles three years earlier than expected. The exponential improvement of battery technologies has continued to expand the range of these vehicles and allowed for smart overnight charging that levels power demand and lowers costs for vehicle owners. Transportation applications and additional applications of nuclear in areas such as desalination have more than offset gains in energy efficiency. Demand growth is expected to continue as fleet electrification increases its penetration and more energy-intensive manufacturing in the Midwest expands.

Concerns over climate change are amplified as average global temperatures have exceeded the 1.5°C increase predicted by some models back in the 2010s and extreme weather events remain a feature across North America. Carbon taxes, employed first at the state level and, as of 2027, at the national level, have negatively affected the growth of fossil-fuel based energy sources including natural gas. Revenues from those taxes have flowed into research and development of clean energy sources, spurring technological advancements in both nuclear and renewable energy.

Events in the United States and abroad over the last decade have emphasized the importance of security concerns regarding infrastructure-focused, physical or cyberattacks. While oil reserves are diminishing, natural gas remains abundant, but, the added security measures for natural gas pipelines has also driven up the costs of gas-based power. These events have also spurred the construction of "grid-adjacent" and off-the-grid power networks for businesses and some communities, particularly in the growth areas of the Southwest and West, with the added benefit of increased reliability.

Renewable sources of energy such as solar, onshore wind, and offshore wind are cost competitive and have reached grid parity, though offshore wind remains socially and politically controversial. The battery breakthroughs that have driven electric vehicles have also served to reduce the intermittency issue for these renewable sources.

Nuclear energy has captured a large part of the rising demand for power. The U.S. federal Government announced a comprehensive energy policy in 2028 committing to nuclear as a long-term solution for energy reliability and low carbon emissions, which encouraged investors and reduced uncertainty for the industry. There are 58 nuclear plants with 96 large light water reactors (LLWRs) in operation. While this represents a slight drop from 2020 numbers, there has been a large increase in advanced non-light water reactors and SMRs with an electricity generation capacity equivalent to almost 20 LLWRs. Smaller reactors and advanced reactors are the primary areas of growth and interest. This renewed interest and acceptance of nuclear energy results in part from the continued emphasis on cleaner sources of energy in this climate-focused political environment, and in part from a shift in mentality towards a longer-term, more risk-tolerant perspective. Indeed, the combination of dynamism in the nuclear power industry and reduced interest in oil and gas has led to a diversification of some of the oil supermajors into the nuclear energy space.

Beyond just electric power production, other applications of nuclear reactors such as co-generation and process heat for industrial processes continue to expand and modular and micro reactors are expected to play a significant role in industrial applications, especially as desalination expands to deal with continued population growth and drought concerns in the Western and Southwestern United States. Significant research in medicine is leading to expanded medical uses of nuclear materials, especially in diagnostics, but it is anticipated that recent advances in genomic medicine health may soon change the landscape of treatment and diagnostics. Space, too, has opened as a nuclear market; NASA, Space-X and the China National Space Agency are using nuclear thermal propulsion technology to power both Mars and deep space missions.

International Nuclear Energy Developments

Globally, the demand for power and for nuclear power is even stronger. The demand for cleaner energy sources has led to a Singapore Accord on climate change as a follow-up to the Paris Agreement. Among the Accord's greenhouse gas reduction measures is the creation of a Nuclear Energy Global Center following the International Space Station collaboration model. This has contributed to harmonized regulations across countries and multinational licensing of some technologies and designs.

The United States continues to share its nuclear expertise with developing nations to foster economic growth and help them achieve their clean energy targets. The 2028 national energy policy included an explicit statement that the United States was committed to a global leadership position on nuclear energy; a fact that geopolitical analysts attributed to U.S. concerns not only with nuclear proliferation, but with China, Russia and, more recently, India's growing global influence and international nuclear energy investments, advisory services, exports, and operations. These governments and their government-sponsored companies are funding significant innovation, especially in fuel types and more non-traditional reactor designs. While the United States has, of late, begun to explore more risk-sharing models of funding nuclear projects, these foreign players remain more risk tolerant and willing to make investments requiring a longer-term perspective for financial justification.

Nuclear Reactor Technology

Nuclear reactor technology has advanced dramatically under this scenario. Advancements in reactor technology have been fostered by regulatory changes like the carbon tax, increased spending on research and development, and entrepreneurs turning their attention to nuclear as an area of opportunity. Licensing and the broader approvals process have, by necessity in this growth market, become faster and more streamlined. The inherent safety benefits of new reactor designs offer an opportunity for further changes in the regulatory environment, while coping with the new innovative technologies and designs brings added regulatory challenges. Meanwhile, critics continue to raise concerns that the slowness of government decision-making and action could choke off growth and investment in the nuclear industry.

SMRs have been certified globally and are becoming more common in developing nations as well. By 2035, planned SMRs will account for close to 20 GWe in the United States, with roughly half of this representing replacement of aging electrical capacity (including now non-economic gas-powered sources) and half a net addition to existing capacity. They are supplying energy for power, but also for other applications, including desalination, that rely on process heat. The smaller size of new reactors means they require less capital investment up front. The standardization of modular reactors has also reduced the cost of these systems by leveraging experience and volume to lower component costs, again reducing capital requirements.

The lower capital costs for SMRs is one piece of the improved economics of nuclear reactors and plants more broadly. Constructions costs have been lowered through use of new materials in plant construction (e.g., the mass-produced carbon fiber reinforcement sheeting now used in engineered construction) and due to a faster and more predictable cycle of approvals. The consistency of ongoing new nuclear plant construction also seems to be stabilizing the nuclear construction workforce in ways that are long overdue.

Innovations and increased efficiencies in fuel and fuel usage are lowering operating costs. Digital I&C as well as greater inherent safety allows new plants to run with leaner staffing, further reducing operating costs.

U.S. local, state, and federal governments have also shown greater willingness to explore mechanisms to share some of the risks of reactor investments, they see the nuclear industry as an essential element of U.S. growth, job creation, and its security has come to be accepted.

As a result, the industry is now an attractive investment target for Wall Street investors, who are pouring billions of dollars into nuclear technology.

Micro-reactors, each producing anywhere from 1 to 20 MW of thermal energy, are an area of major anticipated development. They offer attractive economics, as factory fabrication and the need for fewer specialized operators makes them viable in dozens of potential applications. They offer opportunities for effective off-the-grid use for isolated locations, dedicated on-site power or heat generation, or small communities or industrial plants with strong security or reliability concerns. Portable micro-reactors, for emergency purposes, and even smaller so-called “home reactors” are also proposed. The Department of Defense continues to be a driver of developments and applications for SMRs and micro reactors as it seeks standalone energy capacity. Higher-enriched uranium has been developed and licensed for use in SMRs and micro reactors.

The other area of major development in reactor technology is advanced non-light water reactors, which utilize new fuel types, forms, and coolant technologies. Using 3D, high resolution, multi-physics models and simulations, a diversity of new fuel types and cladding have been developed overseas by government-sponsored projects in China and France. Research reactors in the United States and abroad and, in an increasing number of cases, large production reactors overseas are utilizing new fuel rod designs and new coolants including liquid metal, high temperature gases, and molten salt. Even more speculative technologies, such as thorium-based fission, are at the exploratory stage.

This proliferation of technologies and configurations (many of these approaches, and others, could be applied to LLWRs and SMRs) represent new regulatory situations with much less history to draw upon. However, these advanced reactors are seen to have inherent safety benefits over traditional LLWRs, because of features such as passive safety design and use of accident-tolerant fuels. This has led to industry calls for fewer regulatory requirements for advanced reactors. Currently, most of the more advanced commercial-scale plants are being built overseas. However, as the technologies prove themselves economically viable and safe, applications and are expected to be made in the rapidly growing U.S. electricity market as well.

In summary, nuclear reactor technologies exhibit a dichotomy at this moment in time. On the one hand, greater consistency, and standardization, as seen in SMRs and anticipated in micro reactors, is a major factor driving growth. On the other hand, there is an explosion of new applications and new technologies being explored.

Materials, Waste, Safety, and Security

The growth of the nuclear marketplace in power, health, and newer applications such as rocket propulsion, has attracted investment from traditional industry participants, diversifying large industrial firms and a variety of more entrepreneurial startups. As a result, there are new nuclear products such as accident-tolerant nuclear reactor fuels with silicon carbide cladding which reduce the threat of incidents. There are new nuclear applications emerging as entrepreneurs are introducing additional industrial and medical uses for a proliferating set of nuclear radioisotopes. Finally, there are new vendors and supply chains, like the U.S. aerospace industry and its partners that now supply NASA and Space-X with nuclear engines and fuel.

Consistent with the recognition that nuclear power will be a part of the longer-term U.S. energy portfolio, funding for Congress approved a deep geological disposal repository in 2029. Two Consolidated Interim Storage Facilities (CISF) have also been licensed in the United States. Furthermore, advancements in the reprocessing of spent fuel have contributed to reducing increases in high-level waste.

From a cyber security perspective, bad actors continue to target critical infrastructure, particularly the energy infrastructure including nuclear power plants. However, the nuclear industry is perceived to have been effective in protecting both physical sites and warding off attempted cyberattacks. Other infrastructure systems, particularly those that are more distributed such as the electric grid and gas pipelines, are less effective in securing themselves against threats over the last decade.

Trends in Regulation and Organizations

Regarding government regulation, the United States is expected to build on the trend of the 2020s toward greater tolerance for risk, a longer-term perspective, and a greater willingness to share risk across industry, government, and society as a new generation of leaders continue to establish themselves. Nuclear regulators, like other regulators across government, have systematically embraced more risk-informed and performance-based regulation. This has enabled shorter turnaround times and greater flexibility in approvals, which has both enabled and been necessitated by the growth in the nuclear industry. International standards and regulations are more uniform and there is more consistency across U.S. projects especially with SMRs, which seek to reuse many components, overall designs and common digital I&C.

While the consistent construction of reactors has helped stabilize construction crews, the nuclear industry, academia, and government continue to face increased competition for talent. Those with expertise in new nuclear technologies and applications as well as relevant related fields such as artificial intelligence and simulation are in particularly short supply. As part of the comprehensive U.S. energy policy supporting nuclear energy, subsidies, and grants for research in nuclear technology have funded efforts to expand existing nuclear education programs and to create new programs in universities that have not previously had nuclear education programs. This has expanded and diversified sources of talent in the nuclear field. However, given the time it will take to build up a pipeline of skilled people, talent scarcity is expected to be a concern for the nuclear community into the foreseeable future.

Many firms and some government agencies have responded to talent competition and shifts in employee preferences with what are now well established, short-track positions in which high-skill individuals can join their organizations for shorter, well-paid engagements typically lasting two to three years. This approach has been successful in attracting highly sought-after talent into the nuclear industry, and has resulted in an overhaul of traditional training and knowledge management practices and norms in the industry. Crowdsourcing has also become a proven method for obtaining ideas, funding, and coordinated action in the world of 2030 where many are finding it difficult to hire and retain skilled and experienced people. Crowdsourcing has successfully addressed challenges of surprising complexity. One highly visible example was provided by the Southwest water shortages that finally came to a head in 2026 and were largely resolved through crowdsourcing, prizes, and a combination of government and crowdfunding all initiated jointly by the governments of Nevada, Arizona, and New Mexico.

A move to shorter-term engagements and leveraging crowdsourcing combined with campus-based competitive prizes and more strategic recruiting has made a major contribution to the FDA's efforts to regulate effectively in an environment where they must compete for talent in growth areas of medical innovation. While the NRC has experimented with these approaches, it is not clear how they will fit into the NRC's longer-term solution to coping with the ongoing competition for talent in the nuclear community.

What's Old is New Again

November 30, 2030—Energy demand is rising as the U.S. economy continues to grow while advances in energy efficiency have plateaued. Concerns over climate change and fracking accidents have led to an increased focus on clean energy. While renewable energy is competitive, nuclear power is needed to meet the growing demand. Demand for nuclear from abroad has contributed to the growth of new designs in SMRs, but beyond modularity, nuclear reactor technology has only experienced incremental innovations. However, while these innovations are not disruptive, the improvements in construction combined with carbon taxes and government subsidies have made LLWRs more economically viable to build and operate, and existing LWR facilities are seeking to extend their productive lives. To deal with the spent fuel, two CISFs have been licensed. Although the industry is on an upswing, attracting younger workers to the nuclear industry is a challenge.

U.S. Energy Demand and Nuclear Share of Demand

Since the economic downturn of 2022-23, the U.S. economy has continued to grow rapidly, leading to increased demand for electricity. Advances in energy efficiency, such as smart homes and LEDs, and their market adoption slowed through the 2020s and plateaued in 2028. Twenty-one million autonomous electric cars and trucks are the dominant form of new vehicles on the roads and ride-sharing services become the most common mode of transportation in urban areas. Sales of electric vehicles are expected to continue to increase, and more travel corridors are expected to follow the hyperloop train system model established by California's first-in-the-nation train and the Washington-New York hyperloop currently under construction. These forces, as well as the revitalization of the energy-intensive U.S. fabrication sector should continue to drive demand for power generation for the near future.

Renewables and nuclear power are expected to capture the bulk of this growth. There are continued public concerns over climate change after the hurricane season on the East Coast extended into November for the second consecutive year, this time spawning a category 5 storm. Carbon taxes and carbon limits were implemented at the state level beginning in 2025 and, two years later, carbon taxes were introduced nationally (carbon-discouraging actions are also common globally). Both state legislatures and Congress are using the revenues from carbon taxes for subsidies and research for clean energy sources, including nuclear power. Furthermore, the well-reported fracking accidents that occurred in 2021 have led to increased regulations and controls on natural gas production. In combination, these factors are driving up the price of fossil fuels, including natural gas, and making them increasingly unattractive as a basis for energy generation as a new investment option or even in even as a longer-term ongoing operation. In fact, there are currently three plants seeking approval to convert from gas-fired turbines to SMRs.

The negative incidents surrounding fossil fuels and concerns over climate change have led to a greater emphasis on clean energy sources. Coal is no longer seen as a viable option in this climate-sensitive environment and natural gas is becoming increasingly unpopular, particularly as the public becomes aware of the climate change impact of methane leaks from natural gas production. Renewable energy sources, such as solar and wind (both offshore and onshore), with their clean profile and relatively low construction costs are the preferred alternative of many. However, renewable sources are unable to meet all the rising demand for electric generation capacity. This is due to a combination of their large footprint, resistance to offshore placements, concerns about rising battery material costs and the desire to build long-lived base load capacity that is resistant to potentially changing weather conditions. Despite improvements in battery technologies, intermittency issues remain with renewables. The nighttime recharging of electric vehicles has served to level energy demand patterns somewhat.

As a result, there is an increased public acceptance of nuclear as a viable source of clean energy. Carbon taxes are contributing to increased subsidies for nuclear energy, with both state legislatures and Congress providing subsides for nuclear power plant construction. The LWR fleet remains strong and, while SMRs are increasingly being deployed in applications particularly suited to their smaller size and co-generation potential, the bulk of nuclear power generation capacity is expected to come from extending existing and building new LWRs. Decommissioning has slowed almost to a halt as some planned closures have been reversed and most of plants nearing the end of their license applying for renewals. There are currently 62 nuclear power plants with 101 LLWRs in operation, including several plants that have successfully applied for their 80-year license extension. This total includes two new large light water plants that have recently been completed. Another six LLWRs are under construction or seeking approvals, and even previously mothballed nuclear plant construction sites are being commissioned once again. Where feasible, plants are seeking approval to expand output.

International Nuclear Energy Developments

The international community is also focused on nuclear energy as a clean source of energy, spurring innovation abroad. New designs outside the United States of advanced SMRs have led to an increased number of SMRs in China, India, and some African nations, where their smaller size and lower capital requirements are particularly attractive in less urbanized areas. China and Russia are the leaders in construction and component production in the industry, but the United States is exporting expertise, management, and training to other countries. There is significant global interaction and coordination to address safety and concerns over proliferation, as countries recognize any nuclear-related safety and security incident globally could affect what is now a major export industry for many countries.

Nuclear Reactor Technology

Nuclear reactor technology has undergone limited, incremental advancements under this scenario, which has meant that scale, costs, and consistent production and delivery have been keys to competitive success in new plant construction. This has also encouraged further consolidation among industry leaders and their supply base and discouraged new entrants.

The most visible change has been the deployment and acceptance of SMRs that are certified globally. In the United States, SMRs are being deployed in settings where their co-generation capability can be used for both power and, for example, hot water for industrial heating, as well as in remote settings. Other specialized industrial applications are also being actively explored, most notably desalination in the Southwest where growth, intermittent drought and increasing concerns about sharing water sources have led to current and anticipated water shortages. However, the renewed vitality of existing LLWRs is expected to limit broad deployment of SMRs.

The AP-1000 remains the standard for LLWRs, and is in operation in countries in Europe, Asia, and Africa. While the once-anticipated disruptive breakthroughs in the fundamentals of reactor fuels, coolants, and designs have not materialized, numerous incremental improvements in nuclear and related industries have cumulatively shifted the economics of nuclear plants and reactors significantly. The greater volume and increase in demand for new nuclear plants has enabled economies of scale and leveraged expertise in construction processes across projects. This has helped to foster better commercial program management before and during the construction process shortening time horizons and reducing costs.

The use of advanced materials, including mass production and use of carbon fibers, has lowered overall costs, and accelerated key phases of construction. Cost savings have also come from advances in production processes - especially modular fabrication and additive manufacturing (3D printing) to produce specialized components – and the sourcing of some components overseas to leverage global scale.

Digital I&C adoption coupled with data analytics has led to better management of facilities and contributed to keeping operating costs down for both new and existing facilities. These savings have come primarily through leaner staffing, better optimization of maintenance and improved fuel management.

Improved operating costs, the sunk costs of existing plants and improved construction economics of new LLWRs coupled with government decisions on carbon taxes and renewable subsidies have dramatically improved the economics for nuclear power. However just as important in ensuring the long run vitality of the nuclear industry were three other factors. The 2027 U.S. National Energy Policy not only introduced carbon taxes and renewable subsidies, it also explicitly committed to nuclear power as a critical component of the U.S. long-term energy portfolio. Regulatory approvals and licensing process improvements have helped reduce costs, and they have reduced uncertainty. Finally, interest rates – which have been consistently low for a decade now – not only reduce capital costs but also, by lowering discount rates, increase the value placed on the nuclear facility's longer productive life compared to other power-generating technologies. Nuclear-supportive U.S. Energy Policy, streamlined regulations, and low interest rates encouraged investors to commit to investment in new plants and extensions of existing facilities.

Materials, Waste, Safety, and Security

While congressional funding for a deep geological repository is not imminent, two CISFs have been licensed to deal with the increasing amount of waste. Funding from the U.S. Government has spurred entrepreneurial advancements in innovative new solutions and technologies for storing and/or re-processing spent fuel.

Separate from the forces described earlier, the use of nuclear materials in medical diagnoses continues its rapid growth. To serve this growing market, U.S. firms have developed and continue to expand a competitive and secure supply of Moly-99 within the United States. Competing approaches are currently being utilized by U.S. commercial producers, including accelerator-based and selective-gas-extraction technologies. While much of the world's supply is still sourced from aging research reactors overseas, the United States has become a lead supplier globally providing a more reliable domestic source for U.S. health applications.

New developments in medical uses of nuclear radioisotopes are also finding new health applications. Immunotherapy has been beneficial in extending life expectancy by nearly five years. Improved precision and targeted delivery are increasing demand for more-targeted radiation therapy and diagnostics. In addition, new industrial uses of radioisotopes in mixing and tracing are common in the manufacturing sector. Increased construction domestically is resulting in higher demand for applications such as radiography in pipe welds. The manufacturing sector is undergoing rapid growth because of these new uses and techniques as well as other new fabrication and material advances.

Given the significant interest and growth in nuclear materials nationwide, nearly all states are now participating in the Agreement State Program.

From a security perspective, cyber threats and other threats to physical infrastructure remain an ongoing concern, even as modern IT solutions have evolved to mitigate the threat from cyberattacks. LLWRs and the newer SMEs remain a prominent target of threats from terrorists and other bad actors, requiring ongoing vigilance.

Trends in Regulation and Organizations

Leaders in government and industry have shown increased concern for environmental issues; but have also increased attention on reducing regulation. Regulators, and society, are significantly more risk-tolerant and willing to utilize risk-informed prioritization and decision making than they did ten years earlier. Big data is being leveraged for predictive analytics and being utilized in near-real-time and complete monitoring of facilities and processes. In part based on this better data, regulatory agencies are now issuing longer licenses and easier extensions and renewals. Regulatory agencies are also more comfortable with established protocols for regulating software and digital applications. In addition, the use of third party certification by other parties whether at the state level or overseas, depending on the regulatory environment, is becoming more common.

Finding and retaining the right talent and skills in the nuclear industry, and in government, has become an ongoing challenge in this growth environment. Within the nuclear community, the people with the skill sets needed to build, operate, develop, or regulate LLWRs are approaching retirement or have retired. While educational programs in nuclear engineering and other relevant fields have sprung up or been expanded in response to government and industry encouragement and funds, enrollments are not at a level that will meet future needs. Although government agencies and firms in the nuclear industry are forming partnerships with universities to create new nuclear education programs, this has not been adequate in addressing talent scarcity in the nuclear community. The industry continues to face perception issues in growing its talent pool. Many engineering students interested in energy, for example, prefer to prepare to enter the renewable energy industry, which is seen as more cutting-edge. One approach that has been used successfully in other industries facing a shortage of skilled talent has been the application of artificial intelligence (AI) and robotic process automation (RPA). AI and RPA are used with highly skilled and experienced employees as a means of supplementing and/or augmenting rather than replacing their role. In this way, skilled personnel are freed to focus on higher value activities that require their specialized skills or knowledge. While AI and RPA were widely adopted by industry and some government agencies through the 2020s, their deployment has been very limited to date in nuclear regulation globally, perhaps reflecting the conservatism that characterizes those organizations.

Gone with the Wind

November 30, 2030—The economy continues to grow slowly, and U.S. energy demand decreases due to increased energy efficiency in use, transmission and storage, and a continued shift to less energy-intensive industries. With newer battery technology, solving the intermittency problem of iteratively cheaper wind and solar generators, public opinion and U.S. policy has made a collective decision to shift toward renewables. Despite an increased environmental focus among decision makers, low-cost gas remains a major element in the energy mix while nuclear's share of electricity generation declines as the public and national leaders continue to perceive risks in nuclear energy. Hoped for breakthroughs in advanced reactor performance and nuclear plant construction costs have not materialized. New nuclear plants are being built overseas, but in the United States, the nuclear power industry is contracting and continues to decommission non-competitive reactors. New applications and domestic producers in nuclear medicine provide the largest remaining growth opportunity for the U.S. nuclear industry.

U.S. Energy Demand and Nuclear Share of Demand

Despite a 10 percent increase in population over the last fifteen years, and moderate levels of economic growth, overall electricity demand has decreased by two percent over the same period. Energy-intensive industries like manufacturing remain overseas. Energy efficiency improvements have continued across all aspects of society from LED lighting to smart buildings and home appliances and even to the grid itself. These efficiency gains have blunted the impact of economic growth on energy demand. The anticipated surge in demand from electric vehicles has not materialized: while electric vehicles in the United States have increased from less than one percent fifteen years ago to almost 20 percent today, the significant increases those vehicles have had in efficiency and effective charge utilization have offset the increase in usage.

Demand for nuclear power has also suffered in this environment. Climate change is a moderate political concern, but even with the application of carbon controls on the economy starting in 2027 this has not translated into gains for nuclear energy. Breakthroughs in battery technology have resolved the intermittency problem of renewables, giving society a robust set of low-cost energy options without turning to nuclear power. Natural gas prices remain low as well. While there have been tentative steps towards creating a national energy policy, there is not a perceived need for nuclear power to be a significant component in any such policy going forward.

Groundbreaking on new nuclear reactors still occurs at a limited number of sites, but these are for SMRs that are seeing more widespread application at military sites. The added collective capacity these SMRs represent is offset by continued closures of LWRs. Overall the U.S. nuclear reactor fleet has fallen steadily over the last fifteen years leaving 74 LLWRs still operating. The U.S. nuclear fleet is saved from freefall only by the localized attractiveness of co-locating SMR facilities with factories needing process heat and a regulatory willingness to grant third license renewals.

International Nuclear Energy Developments

Global economic growth and continued global demand for energy drive building a number of new reactors in the developing world. These will be mostly LWRs with SMRs where appropriate in special applications or isolated or small-sized markets. China, with its higher growth in electricity demand and greater government willingness to invest in nuclear power plants, has overtaken the United States in terms of the size of its nuclear fleet, though its own rate of nuclear capacity growth has slowed. New growth opportunities exist in Africa where industry attention focuses on five African nations that are keenly interested in developing nuclear power capabilities. While America continues to be strong in nuclear energy technology and expertise, it is only one among a number of countries looking to export nuclear power capabilities.

U.S. firms, seeing limited markets at home and in the developed world, aim to market themselves primarily overseas and may decide to move their offices or form new venture partnerships offshore as well, but find themselves in intense competition with firms including state-owned enterprises from China, India, and Russia.

Nuclear Reactor Technology

With concern over the intermittency of renewable power generation and the carbon problems of natural gas satisfactorily mitigated, nuclear's relative commercial viability wanes. Government R&D investments in energy is directed toward exciting battery storage technologies which offer a variety of positive impacts including vehicles and reducing the demand for peak capacity as well as continuing to make renewables more attractive. Government dollars also flow to carbon capture technologies through credits and, at the state and local level, co-investment. These battery and carbon capture investments come at the expense of nuclear. There had been some hope of a second nuclear renaissance early in the 2020s, with some supposed technology breakthroughs in non-light water reactors receiving much fanfare and media attention, and with new carbon policies predicted to shift attention away from gas towards nuclear power. However, the hoped-for next generation of nuclear technology has failed to materialize, and the main impact of the carbon policies has been to boost the wind and solar industries. Incremental improvements to nuclear technology, including overall efficiency improvements, adoption of digital I&C, and especially the development of accident-tolerant fuels, are welcomed by existing licensees who are facing massive challenges to their business models, but without a step change in technology, private investment into the industry dries up beyond SMRs, particularly for co-generation applications.

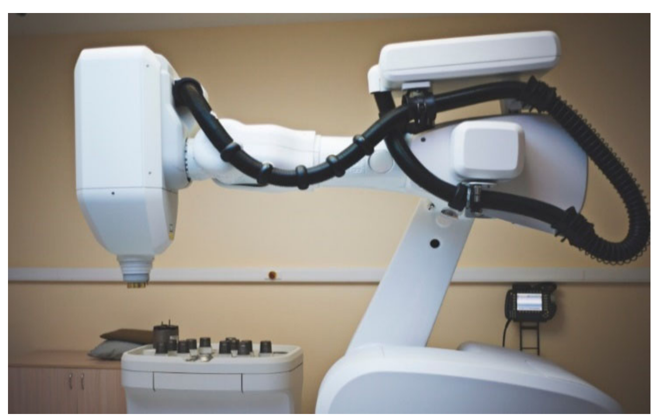
Internationally, thanks to state support and increased expertise from the continued construction and operation of nuclear plants, some countries begin to outpace the United States in sophistication in certain areas of nuclear reactor design and technology. For instance, China has announced that it will put its first traveling wave reactor into service. With different countries taking the lead in different aspects of nuclear technology, national regulatory codes reflect varying levels of technological advancement, and there have been calls for global harmonization.

Materials, Waste, Safety, and Security

Persistent local opposition continues to prevent centralized repositories from becoming a reality, forestalling development of a viable long-term sustainable approach to nuclear waste. Fortunately, cask technology improvements and the slowed rate of spent nuclear material generation by the now smaller nuclear fleet keep the problem of on-site waste storage from becoming more pressing in the near term.

The U.S. public continues to harbor concerns about the safety and security of the nuclear fleet, even though there have been no actual safety or security incidents. The aging nuclear reactor fleet in the United States and elsewhere and the potentially questionable robustness of some developing countries' nuclear safety standards raise public fears of a nuclear safety event. Meanwhile, ongoing risks posed by organized or lone actors with bad intentions and a focus on high profile infrastructure, create further concerns over security. An actual safety event or high-visibility attempted attack anywhere in the world could further reduce the viability of nuclear power under this scenario.

There is a growth area for nuclear materials, however, driven by advances in the use of medical radioisotopes especially in the rapidly expanding field of medical diagnostics. The medical community continues to promote these tests and insurance companies are increasingly providing coverage leading to rapid growth for existing applications. Perhaps even more importantly, commercial, academic and government researchers continue to explore new applications of the nascent technology. To satisfy the resulting growing demand for the technology, the United States has built a reliable,



fully domestic supply chain of Moly-99 and other radioisotopes. This supply chain involves multiple competing commercial enterprises utilizing a variety of processes including accelerator-based and selective-gas-extraction technologies. While much of the world's supply is still sourced from aging research reactors overseas, the United States has become a lead supplier globally. Continued expansion of use in the United States and increased sales into the global market should lead to further growth and new domestic producers emerging in the future. Much of the direct regulation and licensing of these sites falls to the 38 Agreement States in the National Materials Program.

Trends in Regulation and Organizations

Looking ahead, regulatory oversight will be in high demand over the next fifteen to twenty years as the industry looks to decommission much of its fleet. But young, new talent will view nuclear energy as a fading industry in the United States. Budding engineers interested in the energy industry flock to the various renewable energy programs sprouting in universities across the United States, while increasingly the nuclear industry is dependent on an aging workforce. Much of the new talent in the industry comes from the Navy. There is, however, some interest from two-year colleges in creating training programs to support operations and decommissioning work.

Eventually, even decommissioning work will dry up, and with few new reactors coming online to backfill and with technical superiority and expertise migrating overseas, nuclear talent remaining in the United States is likely to turn its focus more exclusively to nuclear medicine. Given these expectations, rumors emerge that oversight of medical radioisotopes might be redelegated to the FDA. With a number of plant owners declaring bankruptcy, think tanks and academics start floating policy ideas such as massive subsidies to preserve at least some part of the nuclear fleet for energy security purposes. Others argue that the United States needs to take steps to maintain and strengthen its nuclear expertise to be able to combat proliferation globally.

Great Idea, But Not for U.S.

November 30, 2030—Energy demand in the United States has plateaued while globally energy demand is still soaring. Concerns over climate change have led to booming demand in renewable energy and carbon capture and storage, but the public does not perceive nuclear power as necessary for climate action, and nuclear's share of U.S. energy generation declines. A few high-profile incidents at international nuclear plants have further affected the U.S. public acceptance of nuclear technology, even though there was little actual threat to safety and security. Reactor technology has advanced dramatically, and the United States continues to be in the forefront of technology development. New plant construction is focused in the developing world, where U.S. firms are in keen competition with foreign state-owned enterprises. The global demand for nuclear has led to a pivot of the U.S. nuclear industry away from domestic construction toward exporting technology and expertise internationally.

U.S. Energy Demand and Nuclear Share of Demand

Even with steady population growth and consistently strong annual economic expansion, the United States finds that its energy needs are at about the same level as in 2000. Key to this trend has been continuing urbanization; 88 percent of Americans live in urban areas characterized by smart cities, broad adoption of urban mass transit, and efficient homes and offices.

Extreme weather events that the public links to climate change have spurred greenhouse gas emission-reduction policy developments at both a state and federal level. States responded to growing public concerns over climate change in the 2020s by strengthening their renewable portfolio standards and boosting the development of renewable energy technology and investing in and/or subsidizing deployment.

Renewable sources of energy such as onshore and offshore wind and solar have thus become cost competitive and have reached grid parity, supported by breakthroughs in battery technology that have also served to reduce the intermittency issue for these renewable sources.

To a lesser extent, breakthroughs in the development of carbon capture and storage, supported by DOE-funded research, have also helped to meet the public's demand for low-carbon sources of power generation making natural gas a more palatable option. For both economic and environmental reasons, gas has largely displaced coal as a fossil fuel source for power generation at this point.

While nuclear energy as an industry is booming internationally, with significant growth in deployment of small modular reactors and micro-reactors, the U.S. public remains significantly skeptical of nuclear power. While there are slight regional differences in the perception of nuclear, the halo of "clean energy" remains limited to renewables, and nuclear is still viewed as risky, particularly because a handful of minor safety incidents at nuclear power plants internationally received disproportionate media attention.

Reading the public mood, the government's new energy policy focuses largely on renewables and natural gas, and significantly cuts its subsidies to existing LLWRs. This results in a number of high-profile decisions by NRC licensees to decommission LWRs which for some will mean exiting the nuclear power industry altogether. Indeed, the industry picture has become so bleak that the Secretary of the Department of Energy mused publicly about the possibility of needing to reintroduce policies to maintain a base level of nuclear power production to ensure diversity within the U.S. energy supply.

The U.S. energy grid itself is increasingly decentralized, including "prosumers" (individual households that are both producers and consumers) generating renewable energy on their own properties. The distributed nature of power generation has reduced the need for large baseload sources of power.

International Nuclear Energy Developments

In this scenario, a voracious appetite for all forms of energy, including nuclear, accompanies continued economic growth in the developing world. In 2027, China passed the United States to become the world's largest economy. Chinese labor markets are now becoming too expensive for energy-intensive manufacturing, and those industries are seeing increased investment in countries such as India, Nigeria, and Indonesia where rates are still affordable, particularly in comparison to U.S. labor rates.

Developing economies around the world have been turning to nuclear to help satisfy their baseload capacity needs, resulting in keen competition between U.S. firms and foreign ones to help build and operate nuclear power plants. Spotting an obvious market opportunity, U.S. firms form consortia to develop next-generation nuclear power technology, including building proof of concept plants in the U.S. to then export overseas. U.S. commercial expertise in SMRs and advanced nuclear reactors has been boosted by research breakthroughs from government-supported investments, such as Department of Defense research into advanced SMRs and micro-reactors.

State-run enterprises in France, Russia, and China, with their ability to leverage state financing to support high capital expenditures and their desire for geopolitical leadership, have dominated the race to build new LLWRs in Africa. However, the market, to date, still consistently views U.S. technology as the superior standard in the newer SMRs and advanced reactors. The U.S. nuclear reactor industry is increasingly an export industry, with a workforce that finds itself building and operating advanced nuclear plants in Africa, Asia, and the Middle East – but rarely at home.

That said, trade skirmishes and security concerns have occasionally prevented the United States not only from exporting new nuclear technology but also from importing new technologies developed abroad, such as advanced digital I&C.

Nuclear Reactor Technology

Nuclear reactor technology has advanced dramatically under this scenario. In the 2020s, U.S. firms saw growing revenue from the sales of traditional LLWRs to the developing world, which encouraged focus and investment in nuclear innovations. The company dollars were supplemented by direct research investments and subsidies by the federal government during the early 2020s. Most of that funding, with the exception of defense spending, has now fallen away as the U.S. government has shifted away from nuclear to renewable energy. This research, paralleled by government-led efforts in China, Russia, and India, led to the collective breakthroughs in the mid-2020s that brought Generation IV (Gen IV) reactors into reality.

The Gen IV reactors comprise a variety of non-light water technologies, such as advanced gas-cooled reactors and molten salt reactors. U.S. firms have begun aggressively marketing their diverse portfolios of new technologies around the world, with signed agreements to construct and/or operate dozens of new reactors throughout the 2030s.

In the economics of nuclear plants, there is a distinct split in the costs of LLWRs and SMRs / Gen IV reactors. Capital and operating expenditure costs for large nuclear power plants continue to increase, while a combination of small size, modular construction and a quick learning curve has caused construction costs to iteratively decrease for SMRs. Artificial intelligence and automation have also brought down operating costs and increased efficiency for SMRs and advanced reactors. This has led to what nuclear power demand there is in the United States increasingly being generated by SMRs and advanced Gen IV reactors, not existing or new LLWRs.

Materials, Waste, Safety, and Security

In this scenario, there is reduced demand for nuclear radioisotopes for medical therapeutics and less broad-based usage in diagnostics due to the proven effectiveness of genomic medicine. Increased use of genetic markers in diagnostics and targeted treatment as well as gene therapies have reduced demand for nuclear materials and these successes have redirected research grants to pursue potential gene-based breakthroughs. This has resulted in the decommissioning of reactors producing radioisotopes. Citing funding concerns from reduced licensing revenue, a handful of states have decided to cease participation as Agreement States, returning responsibility for licensing and inspection of nuclear materials in those states to the NRC.

There is growing public concern over on-site storage of nuclear waste, but there are contentious debates within and between the Administration and Congress and between federal and state leaders over the appropriate policy approach high or deep geological waste repository. This ongoing debate leaves funding for any such repository in limbo. What unifies the public is a general agreement that with no long-term solution in sight, increases in on-site waste should be actively discouraged. This provides another incentive to reduce the number of nuclear power plants in operation.

While the new plants with Gen IV reactor designs are inherently safer and structurally more secure against both physical and cybersecurity threats, this has not deterred bad actors from intensifying threats to nuclear plants, including the use of drones and other unconventional security threats. The U.S. public conflates threats to older LWRs with threats to all nuclear power plants. Further, the public and the media tend to blur the distinction between threats on or around a nuclear plant site with threats to the reactor. Anxieties stoked by media coverage of a cybersecurity incident in a plant overseas, even though ultimately resolved safely and shown to have been caused by simple human error, have intensified U.S. public wariness of nuclear power.

Trends in Regulation and Organizations

The push for regulators of all types to adopt more nimble, flexible, and performance-based approaches has continued to increase over the last decade. This pressure has intensified from the nuclear industry coming from American firms eager to construct a small but respectable number of next generation reactors in the U.S. so they can pursue foreign contracts and from operators of financially troubled existing plants trying to remain economically viable.

U.S. regulation of the nuclear industry has responded to this pressure through improved speed and a more risk-informed, streamlined process; a process that is still slower than that of many foreign regulators. The U.S. and foreign regulators continue to work out the finer points of regulating the new technologies and designs distinct to their countries producers and construction. Foreign regulators seek American expertise as they adapt their own regulatory frameworks to the new technologies and, to a lesser extent, the U.S. does the same. Complementing this effort, the greater internationalization of components within nuclear power plants has resulted in more harmonized international standards and better-aligned regulations.

In the United States, U.S. firms focus their new license requests on building proof-of-concept plants for the imprimatur of U.S. regulatory approval. Similarly, foreign nuclear firms playing catch-up to U.S. technology seek U.S. regulatory approval of their new reactor technologies despite never intending to market these technologies in the United States in any significant way. This is partly because their own regulators are behind the curve on these new technologies and partly because these firms want the brand name that U.S. regulatory approval carries. Indeed, the plethora of advanced technology has also required a shift towards performance-based regulation. This has enabled greater flexibility in approvals and has required a more adaptive and international mindset.

The nuclear community continues to face increased competition for talent. There is competition within the industry and between industry, academia, and government. There is also competition with other components of the energy industry such as renewables and other sectors that utilize talented individuals. Nuclear engineers with experience with new applications and technologies such as AI and modelling/simulation with applicability across industries are in particular short supply. Firms "poaching" talent from regulators and academic institutions has become a standard practice in the global industry. Some Americans have started pursuing nuclear programs in prestigious foreign universities such as Sciences Po in France and the University of Science and Technology of China. Talent scarcity is expected to be a concern for the industry into the foreseeable future.

The nuclear industry has attempted to respond to competition for talent, the growing internationalization of the industry, and shifts in employee preferences by shifting to a global talent model similar to the oil industry. This model involves global recruiting, regular job rotation, and frequent on-demand trainings. It both fosters and requires adaptability and an understanding of how to be successful both in the United States and internationally. It is less clear how this solution might be employed by regulators in a security sensitive environment.

Nuclear Futures — NRC Implications

Having developed the four potential future scenarios, it is critical to understand what impact these scenarios will have on the NRC going forward. An understanding of such implications can help the NRC determine what actions it can take to be prepared for success in these scenarios. Over the course of several workshops, NRC staff and senior leadership reviewed the four future scenarios that were developed and identified the impact on the NRC's business lines, product lines, and corporate product lines under each scenario. Figure 4 summarizes the broad challenges presented to the NRC in each scenario. The detailed implications are delineated in the tables that follow.

Figure 4: Core Challenges

High

U.S. Nuclear Power Demand*

Low

Global Reactor Innovation**

Incremental innovation only

Disruptive & incremental innovation

What's Old is New Again

Under this scenario, the NRC will see the profile of the domestic nuclear fleet expand and become inherently safer as new SMRs sprout up across the country. While the expansion and increased safety of the U.S. nuclear industry is welcomed by the NRC, much public outreach will need to be done to ensure the public is adequately on board with the industry's evolution. On the international front, global technological advancements outpace those in the US. The NRC desires to remain a world leader in new reactor design review, but it also debates whether it is better served accepting reviews performed by other countries who are more knowledgeable about the leading technologies. Greater international and multilateral cooperation among trusted foreign partners will be in the NRC's best interests if it intends to have a say in ensuring safety and security in the global nuclear energy industry

Nuclear Takes Off

Under this scenario, the NRC must deal with a significant activity expansion, an increasing proliferation of reactor types and sizes, and new applications for nuclear materials in non-power health and industrial uses. The funding of a deep geologic repository will drive an additional stream of activity for the NRC. Different forms and applications present different risk profiles requiring an "it depends" approach to regulation and, for some technologies, calls for taking a clean-sheet approach to determining requirements and processes for licensing, rulemaking, and oversight. The NRC's licensing must be more predictable and more streamlined for this growth of the nuclear industry to take place. Retooling the oversight philosophy toward a more agile and risk-informed model will be needed to provide timely and efficient oversight

Gone with the Wind

Under this scenario, the NRC must deal with a significant decrease of new licensing activity and turn instead toward license renewals for an aging reaction fleet and decommissioning. Though overall workload will decrease, much work remains, particularly ensuring the safety of an aging fleet and the orderliness of decommissioning. The NRC will acutely face the pressure of constrained budgets, and it will need to be strategic and innovative in how it deploys its now more limited resources to satisfy its mission of maintaining public safety. Retooling the oversight philosophy toward a more risk-informed model will make sense for both the NRC in this limited-resource environment and for operators who are struggling to compete. Meanwhile, the NRC will no longer be able to take its global leadership in the nuclear industry for granted, and if the U.S. is interested in maintaining influence in the field, the NRC will need to think critically how to cooperate with international and bilateral partners

Great Idea, But Not For U.S.

Under this scenario, the NRC must deal with a situation where there is a slowdown of activity domestically at the same time as a significant expansion of activity internationally. The NRC's ability to support the U.S. nuclear industry as it pivots to focusing on exporting advanced technology to the international market requires the NRC itself to adopt a more international-facing role, with attending impacts on the way it conducts licensing and rulemaking such as focusing on harmonizing international standards. Conversely, domestically, U.S. public wariness of the nuclear industry may require the NRC to play a more proactive outreach role to reassure the public of the safety and security of the U.S. nuclear reactor fleet. These significant changes to the NRC's focus also challenge the NRC's current business model and its dependency on fees from licensing domestic reactors

Impact of the Future Scenarios on the NRC's Business Lines

Table 1: Impact of the Future Scenarios on the NRC's Business Lines

Business Line Affected	**Nuclear Takes Off**	**What's Old Is New Again**	**Gone with the Wind**	**Great Idea, But Not for U.S.**
Operating reactors	Extended reactor lives, digital I&C adoption and exploration of other innovations (e.g., AI) require additional resources and potentially new skills.	Extended reactor lives, digital I&C, and increased international cooperation to develop and harmonize standards will require additional staff who will be utilizing more data and technology intensive streamlined processes.	Fewer operating reactors will call for new ways to approach regional structure and event response, while an aging fleet will present new oversight responsibilities.	A decline in LLWRs leads to reduced licensing actions and renewals, and a need for a smaller licensing organization. This will have a strong impact on the NRC's business model.
New and advanced reactors	Large numbers, new technologies, and diversity of designs call for increased capacity and new approaches by the NRC.	New rules and processes are needed to regulate SMRs where there is less accumulated experience, but the same streamlining approach is being pursued while attempting to leverage data internationally to accelerate learning.	Limited new reactors requiring licensing will result in resources being directed to overseeing existing reactors.	New technologies and diversity of designs call for more flexible licensing approaches, and for new skillsets to be able to certify diverse designs. Growth of technology internationally requires more cross-border collaboration.
Nuclear materials users	New and innovative industrial and medical applications mean new skills are needed to regulate new types of organizations in new locations.	New medical and industrial entrants and uses creates a staffing challenge in numbers and skills in this environment where all states are now Agreement States which the NRC may seek to address through partnerships (e.g., with FDA).	Anticipated greater uses of medical radioisotopes will require new NRC skillsets, different from traditional nuclear engineering.	The ultimate impact on workload for the NRC depends on the balance between having fewer materials users to inspect due to decreased medical and industrial uses of radioisotopes and having more responsibility from oversight return from Agreement States.

Business Line Affected	**Nuclear Takes Off**	**What's Old Is New Again**	**Gone with the Wind**	**Great Idea, But Not for U.S.**
Decommissioning and low-level waste	No significant change to this area as despite the preference for new reactors, growing demand keeps many operating reactors viable.	Not a major factor in this high-growth scenario, but when decommissioning is done there may be more self-regulation with NRC involvement in higher-risk activities, e.g., fuel moves and vessel sectioning.	Decommissioning workload to increase in future for the NRC, with workload only stemmed by extended license renewals. Waste production continues but is limited as few new plants are commissioned.	Increased decommissioning-related licensing and oversight workload and more low-level waste related to decommissioning, though less low-level waste related to other uses of nuclear materials.
High-level waste	Creation of a deep geological repository will require short-term technical, adjudicatory and stakeholder communication skills and activity, followed by longer-term rules and inspection of both the deep geological repository and interim storage facilities.	Licensing and oversight of the two CISFs will be important to not only perform effectively but to communicate effectively to the public while other long-term solutions will continue to be explored hat may require ongoing NRC work.	High-level waste production continues but is limited as few new plants are commissioned. However, there may be a greater need to deal with high-level waste at decommissioned plants.	Lack of agreement on a deep repository requires NRC outreach to improve public understanding of high-level waste storage, particularly if increases in decommissioned sites results in continued onsite storage of high-level waste.
Spent fuel storage and transport	Increased volumes, transport, and new fuels will prompt innovation and require research, rulemaking, and training relating to new/revised package and storage designs for new fuels and new and old spent fuel.	Increased transport and new package and storage designs will require research, rulemaking, training, etc. and outreach to those at the storage site and along the route while demonstrating a rapid response capability.	Decreased in activity in nuclear reactor sector reduces volume of spent fuel produced and keeps on-site waste storage from becoming a more pressing problem in the near term.	Given public skepticism of anything to do with nuclear power or energy in this scenario, the NRC may also need to significantly enhance public outreach and messaging to reassure the public of the safety and security of existing spent fuel storage.
Fuel facilities and reprocessing	New and revitalized fuel production and innovative reprocessing will trigger the need for construction oversight, licensing, operations oversight, research and rulemaking and coordination with the DOE and other organizations.	High demand for fuel leads to new fuel facility construction requiring additional regulatory rulemaking, oversight, training, outreach, etc. with the potential for Agreement States to play a role.	U.S. firms shift focus to marketing overseas as domestic market remains weak, causing the NRC to adapt to international trade context while also managing proliferation concerns.	With lower fuel demand, the NRC will have to prepare for the shutdown and decommissioning of fuel reprocessing facilities. The continued contraction of the fuels industry may push the fuel budget off the fee base.

Impact of the Future Scenarios on the NRC’s Product Lines

Table 2: Impact of the Future Scenarios on the NRC’s Product Lines

Product Lines Affected	**Nuclear Takes Off**	**What’s Old Is New Again**	**Gone with the Wind**	**Great Idea, But Not for U.S.**
Event response	New sites to cover and greater weather event concerns have implications for resource requirements and priorities, and require rethink of event response models e.g., to rapidly deployable “tiger teams.” Inherent risk of event remains.	Increased research to support event response in urban areas for SMRs and nuclear plant programs will be emphasized because of fossil accidents.	Reduced resources and a smaller nuclear reactor fleet puts pressure on how event response occurs, with rapidly deployable “tiger teams” being a possible model to explore.	Fewer reactors in the United States. may reduce the need for domestic event response, though the NRC’s workload related to international event response may increase.
International activities	Greater global innovation and growth call for more international activity and coordination for the NRC.	The NRC will work to maintain its higher standards as a regulator and remain a leader in international activities.	Nuclear industry talent migrates overseas to where new nuclear development occurs, and U.S. reactor and materials firms reorient their marketing efforts internationally. The United States puts resources into continuing to influence international standards where possible.	Nuclear innovation is happening globally, prompting a need for increased international cooperation and assistance including development of terminology/ frameworks/requirements for harmonized standards for diversified technology. In terms of talent, an international detail may become an important, and even routine, part of an NRC career. There may even be interest from other countries pursuing advanced nuclear technology without a strong regulatory infrastructure in paying the NRC to play an oversight role outside the United States

Product Lines Affected	**Nuclear Takes Off**	**What's Old Is New Again**	**Gone with the Wind**	**Great Idea, But Not for U.S.**
Licensing	Increased workload with novel issues for a variety of new designs and applications from SMRs to advanced reactors results in the need for risk-informed, streamlined licensing processes and decisions.	Increased licensing for reactor renewal, for other areas of the fuel cycle for power, and for medical radioisotopes will need to be supported by a more streamlined, predictable, risk-informed, and performance-based process as well as possibly greater use of third parties.	Significant reduction in number of routine licensing actions, with focus primarily on complex licensing actions. Migrating talent and reduced resources make a contracting model more attractive for performing license work.	Licensing focus shifts from operating reactors to new designs and applications, including approval of proof-of-concept designs. This may require more performance-based licensing processes and decisions. There will also be increases in licensing related to decommissioning and spent fuel. International innovation may require considering adoption of other countries' license approvals, or global harmonization of standards.
Oversight	Expanded sites, designs and applications call for a rethinking of the approach to oversight that reflects true risk profile of each technology and situation.	To cover the increasing level and diversity of oversight needs, the establishment of a risk-based approach for each technology and situation will be needed for effective oversight along with reconsidering deployment.	Pressures on oversight capability in the context of reduced labor force and resources can be mitigated by new inspection models, including using risk-informed oversight and new digital I&C.	Oversight workload may be reduced from the fewer operating reactors, though there will be increased oversight of decommissioning and spent fuel, and new skills needed to oversee the handful of advanced reactors operating in the United States.
Research	Innovation and new practices will call for research and portfolio management across areas including new fuels, construction materials, reactor designs, uses of AI and RPA, adoption of digital I&C, etc.	While disruptive innovation does not characterize this scenario, there is still a need for new research in a variety of areas, some new to the NRC, suggesting a greater need for collaboration in the future.	Greater reliance on trusted international partners for new and advanced technologies, but aging reactor fleet will call for research into safety of continued license renewals, as well as into long-term on-site fuel storage.	Disruptive innovation in this scenario will call for research into many areas. However, the NRC may need to obtain research support from other countries, or co-fund research with other foreign regulators or research agencies.

Product Lines Affected	**Nuclear Takes Off**	**What's Old Is New Again**	**Gone with the Wind**	**Great Idea, But Not for U.S.**
Rulemaking	New rules needed in a variety of areas from digital I&C to advanced reactors to transportation packaging. Rules should be built from first principles informed by relevant risks.	Increased foreign investment and new technologies will requires revisiting regulations, guidance, and inspection oversight to ensure they are current with the times.	Industry desire to shift toward a more risk-based model and a desire to implement more digital I&C will require new, adaptive rules.	Rulemaking in an environment of international innovation requires an approach that relies less on the NRC's ability to set the rules in the domestic context, and more on the NRC's ability to cooperate with trusted international partners and lead internationally to persuade other international agencies to adopt common standards.
Training	New technologies and applications will call for new training topics and new hiring, career, and onboarding models will require flexible approaches to training methods, design, and delivery.	Advances in technologies and applications will call for new training topics and new hiring, career, and onboarding models will require flexible approaches to training methods, design and delivery.	Training will have to address the problems stemming from an increasingly aging nuclear fleet, and a changing geographic makeup of the workforce will require a changing way of delivering high-quality training.	Advances in technologies and applications will call for new training topics and flexible approaches to training methods, design and delivery.
Relations	As the nuclear industry expands, it will be necessary for the NRC to focus on the relevant state and tribal stakeholders, particularly with regard to repositories.	Aggressive outreach to state, local, and tribal will be needed as reactors are decommissioned and fuel is transported for disposition,	Increasing, persistent on-site storage will continue to spark local opposition, requiring greater public outreach from the NRC to explain how it safeguards nuclear safety and security.	The NRC may have less specific licensee interaction with state and tribal stakeholders but may need to more proactively address the concerns of the public with regards to nuclear safety and security.

Impact of the Future Scenarios on the NRC's Corporate Product Lines

Table 3: Impact of the Future Scenarios on the NRC's Corporate Product Lines

Corporate Product Lines Affected	**Nuclear Takes Off**	**What's Old Is New Again**	**Gone with the Wind**	**Great Idea, But Not for U.S.**
Administrative services (e.g., facilities management)	A deployment-based structure with greater flexibility to respond to program needs, versus geographic needs, may be required to face increased volume and shifting geographies.	The NRC may need to develop and frequently revisit a long-term space plan to predict needs early and optimize real estate footprint and maintain flexibility based on size, activities, and working styles (e.g., teleworking, hoteling, etc.)	With fewer staff, physical footprint of NRC headquarters will need to decrease. This may be addressed through greater telework/hoteling arrangements at HQ itself combined with greater decentralization.	With fewer staff, the NRC may need to reorganize and consolidate its regional structure.
Financial management and budget	Portfolio-optimizing budgeting, streamlined financial systems, and automated invoicing may be necessary to remain focused and agile in the face of many emerging opportunities/needs and changing circumstances.	Fees deliver more dollars, yet budgets are likely to remain tight and uncertainty remains regarding future technologies which requires more "what if" examination and attention paid to the strategic implications of decisions.	With a more uncertain workload, performing tasks through contracting gains appeal.	The NRC will have to work within a reduced budget through efficiencies such as shared services and through revisiting its business model.
Human resources management and training	Increased NRC staff size is needed. The NRC will need to rethink its approach to HR and training to successfully deploy the skills and numbers it will need in this highly competitive talent marketplace.	The NRC will need to rethink its approach to HR and training to successfully deploy the skills and numbers it will need in this growing environment and highly competitive talent marketplace.	Reduced NRC staff size. Attracting young talent with the expectation of them staying for their entire career will become very difficult; instead, will need to allow for a more transient workforce. In many cases, temporary employees may have to fill gaps, and some training will need to be outsourced to other agencies given resource constraints.	Reduced NRC staff size. Reduced workforce needs mean the NRC will need to consider which jobs can be performed through contracting. There may also be a significant international component of an NRC career, including rotations with international agencies

Corporate Product Lines Affected	Nuclear Takes Off	What's Old Is New Again	Gone with the Wind	Great Idea, But Not for U.S.
IT / IM resources	IT / IM deployed throughout the NRC can address the skills and productivity challenge through easy data access from anywhere, AI, RPA, and data analytics and mission-focused apps developed using new skills in-house or externally.	The NRC can utilize modernized IT / IM embedded in the organization to improve knowledge management and augment work through big data and analytics, AI, and RPA to enhance productivity and risk-informed decisions.	More efficient data management and archiving technologies will need to be implemented, and Big Data applications will be able to alleviate resource constraints in oversight.	Technology can augment the NRC's ability to do more with fewer people, through means such as data analytics and remote monitoring.
Policy Support & Legal	New energy policies and new regulations to address new technologies, storage, transport, medical and industrial applications may be required.	Opportunity to revisit policies with science-based guidance; changes might include extending term limits, rethinking foreign ownership, and legislative changes to facilitate flexibility for SMR designers.	Large-scale rulemaking will be curtailed given resource constraints, but international and multilateral cooperation will expand as firms look to conduct trade abroad. Some functions may need to be re-legislated to other agencies.	Policy support and legal will require an international dimension to the work under this scenario.
Outreach	Outreach will involve social media and new digital tools (e.g., virtual reality) and will include many constituencies including current and new universities, government agencies and decision makers, industry, and the public.	There will be more Atomic Safety and Licensing Board (ASLB) hearings and an ongoing need for public education, but these will employ new technologies including next-generation video conferencing, crowdsourcing, social media, and virtual reality, as well as technology still to be developed.	Outreach will involve a variety of cost-effective tools and will play an important role in communicating with local communities on issues related to decommissioning.	Outreach for reassurance of the safety of nuclear will be a key part of the NRC's work, and will involve social media and new tools.
Integrated University Program	The Integrated University Program could play a more significant role in this scenario regarding the development of technologies and access of new and scarce skills	Funding may increase to support national needs for engineers and IUP could evolve to meet needs for more cutting-edge disciplines impacting nuclear-related activities, e.g., safety/security assurance, data analytics, AI, etc.	Scholarships and other relationships with universities can play an important role in ensuring a pipeline of nuclear talent and, ultimately, maintenance of nuclear technical knowledge.	The Integrated University Program was not judged to be an impacted area under this scenario.

Impact of the Future Scenarios on Other Areas

Table 4: Impact of the Future Scenarios on Other Areas

Other Areas Affected	**Nuclear Takes Off**	**What's Old Is New Again**	**Gone with the Wind**	**Great Idea, But Not for U.S.**
Culture	The NRC will have to focus efforts where they matter most, and evaluate new designs and operations based on their merits rather than past practices. Culture shift required away from formalized training to experiential learning and mentoring.	The NRC culture could flounder due to coping with ongoing uncertainty and a need to adjust and adapt to more risk-tolerance and reduced regulation.	With fewer staff, the NRC may have to re-tool its culture to shift attention to its primary focus of decommissioning.	A leaner NRC staff could result in a culture of greater use of outside resources such as contractors. The international focus of the NRC will need to be much stronger.
Organization	New workstreams in new areas of the country requires relooking at organizational structure, decision rights, and work management.	A shift toward an agile, "tiger team" approach that is flexible and focused on outcomes will be needed versus the current branch-based structure.	HQ will look to shrink its footprint in the metropolitan Washington, DC area, and regional consolidation may also need to be explored.	This scenario requires rethinking of a number of aspects of NRC's organizational structure, including the regional structure, the need for a matrixed approach to areas of responsibility and areas of expertise, and the need for an organizational structure that understands and rewards cross-border work.
Workforce	Need to maintain and expand knowledge and skillsets even as experienced employees retire. Need to adapt to attract highly skilled younger workforce and make use of outside resources.	The NRC will be challenged to maintain and expand its knowledge and skillset as experienced employees retire, technologies stagnate, and the "NRC value proposition" is unclear. A smaller government workforce is likely with the hiring of outside, specialized resources on an as-needed basis.	Staff continues to age, with new recruitment remaining limited. Some talent may be able to be recruited from decommissioning reactors, but new talent at the NRC will call for decentralized working arrangements.	The NRC will be challenged to maintain its knowledge and skillset as its constraints as a government regulator may be at odds with the changing norms of the nuclear industry. It may find itself focused on attracting mid-career entrants to the NRC.

Other Areas Affected	**Nuclear Takes Off**	**What's Old Is New Again**	**Gone with the Wind**	**Great Idea, But Not for U.S.**
Leadership & decision making	Leadership needs a clear vision and priorities. Leadership's ability to make decisions promptly while maintaining flexibility will be critical.	Leadership needs to evolve to greater, risk-based regulatory decision-making. The widespread adoption of analytics will lead to more fact-based decisions at lower-levels of the organization.	Leadership will need to maintain a strong, convincing vision as NRC's workforce shrinks and becomes more geographically dispersed.	This scenario does not have obvious precedents in either past boom periods or past slumps in the nuclear industry. Itis important to have leadership that keeps the organization on track in an environment that offers many demands and opportunities but in ways that may not fit with the NRC's traditional business model.
Governance & stakeholder engagement	While there are changes in public opinion and policy, not all stakeholders will move at the same speed and groups who intentionally or unintentionally spread false information could impact the NRC's ability to act.	The need to establish a broader set of domestic and international stakeholders will present new requirements. Current governance structures will likely be antiquated due to emerging needs across the United States and efforts to standardize internationally. Engagement will also have to be rethought as the medical and industrial sectors usage of nuclear materials expands.	In this scenario, stakeholder engagement will be critical to ensure that the public feels adequately protected in the context of multiple decommissioning reactors.	Congress will play a critical role as the NRC seeks both to invest to keep pace with emerging demand and technologies and as the NRC seeks to reassure the public of the safety of the U.S. nuclear reactor fleet.
Budget & statutory mandates	Continued effective interactions with the Hill needed for a budget that permits necessary investments and the retention/ expansion of staff expertise, and to support informed formulation of energy policy and regulation.	With the need to expedite licensure, Congress will likely eliminate requirements for mandatory hearings, for new facility licenses.	Decreased budgets will stress the fee-recovery model and will create pressure for the federal government to provide funding to ensure minimum safety. Sharing resources with other federal agencies will be explored.	The NRC will need to work within increasing budget and statutory constraints while also looking at the fee structure in an environment where the NRC's workload has shifted away from its fee base.

Other Areas Affected	Nuclear Takes Off	What's Old Is New Again	Gone with the Wind	Great Idea, But Not for U.S.
Security	Cyber security threats continue to rise with the expansion of digital technologies such as those leveraged for reactors, and new digital medical devices that use nuclear materials. Increased resources are required to support oversight of robust security programs.	Cyber security threats continue to rise with the expansion of digital technologies such as those leveraged for reactors, and new digital medical devices that use nuclear materials. Increased resources are required to support oversight of robust security programs.	Although cyber security threats continue to rise with the expansion of digital technologies such as those leveraged for reactors, and new digital medical devices that use nuclear materials, the smaller number of plants results in a reduced footprint for oversight by the NRC.	Although cyber security threats continue to rise with the expansion of digital technologies such as those leveraged for reactors, and new digital medical devices that use nuclear materials, the smaller number of plants results in a reduced footprint for oversight by the NRC.

Key Takeaways

After exploring how the external environment in which the NRC operates might evolve and the implications of those scenarios on the NRC, there are a number of considerations in terms of the potential options for the NRC to meet the challenges of a changing industry, improve delivery on current and future missions, and prepare its workforce for 2030 and beyond.

While the future external environment in which the NRC will operate in 2030 is uncertain, it is far from entirely random. Monitoring and preparing for how the future will unfold can allow the NRC to be more agile and resilient to the range of possible futures, placing the NRC in a far better position to thrive regardless of whatever future emerges.

Common Themes

Below are the key takeaways, grouped by theme, from the scenarios and their implications. While the implications for the NRC vary under each scenario, certain common themes emerged. These themes represent areas where the NRC may want to consider taking action to prepare for the future. Broadly speaking, the implications for the NRC fell into five thematic areas:

- Increasing the Agility of the Organization;
- Enhancing the NRC's Strategy, Governance, and Culture;
- Preparing for Human Capital Changes;
- Increasing Efficiency Through Technology;
- Engaging with Future Stakeholders.

Increasing the Agility of the Organization

Based on the implications outlined, the NRC's need for increased agility (i.e., the ability to act quickly and easily) in the world of 2030 was a common and important theme across all four scenarios. Within each scenario, there is a premium on agility stemming from the need to ramp up or down certain activities in response to changing demands, as well as from requirements for new approaches in response to anticipated innovation in nuclear technologies and reactor design. The NRC may need to adjust in the future to create accountability for the agility required to support the changes described earlier in this document. The NRC may also need to adapt to new types of licensees and business models, more performance-based regulatory approaches, a shifting portfolio with regard to reactors and nuclear materials and so on. The need for agility becomes even more striking when looking across scenarios and recognizing that the path forward is likely to twist and turn, potentially shifting from one scenario to another in response to changing circumstances and/or precipitating events.

Enhancing the NRC's Strategy, Governance, and Culture

Addressing the NRC's strategy, governance, and culture to prepare for the potential external environment of 2030 and beyond was also a common theme that emerged both within the identified scenarios and across the set of possible futures. Changes in technology being licensed, demand for key activities such as decommissioning or licensing, and licensee business models in the scenarios mean that broadly, the uncertain future will call for an increasingly adaptive strategy, governance that accommodates the anticipated rate of change, and a culture that is more flexible going forward. These are not so much criticisms of any past practices as they are recognition that the areas addressed by the NRC's mission could evolve rapidly in coming years. Across the scenarios, the importance of expedient, transparent decision-making and the need to reduce a risk averse culture are noted. An increasingly adaptive strategy including risk-informed and performance-based approaches to regulatory oversight, governance that accommodates the anticipated rate of change, and a culture that is more flexible going forward are needed to support a dynamic, uncertain future with rapid and potentially non-linear evolution of the nuclear industry and related technologies.

Preparing for Human Capital Changes

Human capital is another critical theme that emerged across all scenarios due to changes in workforce levels at the NRC, as well as the projected difficulty in retaining and attracting talent. Transparency and sharing information early remain key to building a foundational trust. In shifting from an aging workforce to a younger generation, attracting, developing, and retaining the right talent and knowledge is critical to meeting the NRC's evolving mission, though what constitutes the "right" talent and where that talent should be source from will vary depending on how the future unfolds. There is a clear recognition that the NRC workforce draws from much of the same pool of talent as the nuclear industry as a whole, and needs to adapt its hiring practices to trends within the industry, as well as to trends in the federal workforce. The NRC workforce will also have to adapt to broader trends in the U.S. workforce, including technological and generational trends – by 2030, for example, Gen Xers are starting to retire, and many millennials are occupying positions of senior leadership across organizations. This will affect how the NRC thinks about retention, including rethinking the traditional NRC career model.

Another common theme across the scenarios is how the NRC will develop and retain the skillsets it needs, even as the specific skillsets needed vary across scenarios. This includes building on the work that the NRC has done to adapt to trends in training and knowledge management for the NRC permanent staff. It also includes looking at other options besides permanent staff that the NRC can use to augment staff capabilities such as technology, contracting, or crowdsourcing. The NRC is currently preparing to address expected human capital changes by incorporating an eSWP strategic workforce plan.

Increasing Efficiency Through Technology

In each scenario, the need for the NRC to increase efficiency through technology is also highly evident. All four scenarios envision a world in which the technology available to support enterprises and regulators continues to grow exponentially in capability between the present day and 2030. In particular, data analytics, cognitive technologies such as AI and RPA can enable the NRC to be more efficient. Knowledge of technologies that reduce the need for physical presence such as remote sensing/monitoring and modelling/simulation will equip the NRC to understand licensee use of these technologies. Cybersecurity and information classification play an important factor when considering leveraging these technologies to avoid the potential for adverse impacts to safety and security.

Engaging with Future Stakeholders

Lastly, engaging with future stakeholders is also a critical theme that emerged in all four scenarios. The NRC is part of a broad ecosystem in the nuclear industry that includes government entities (international, federal, state, local, and tribal), private sector organizations, academia, and volunteer organizations. Across all four scenarios, stakeholder engagement and transparency in the future will remain an important element as the NRC interacts with a more diverse set of stakeholders, and engages them through new communication platforms, as stakeholders become partners and advocates for change as the industry deals with uncertainty. The NRC will also have to continue to focus on being transparent as it faces greater calls for more openness. A related sub-theme that arose in the scenarios was the need for increased collaboration with international bodies, including the possible need for harmonized international standards and aligned regulations. The NRC's future engagement with stakeholders will build on the extensive effort the organization is currently undertaking.

Considerations for Action

Actions and options in these five thematic areas can help the NRC better prepare for the range of potential scenarios that were developed. Some of these actions will be robust, and apply across the four scenarios regardless of which future unfolds. Other actions will be agile actions, to keep the NRC ready to adapt and respond quickly to multiple futures. Yet other actions will be "hedges" that the NRC could take to prepare itself to respond for particular futures, or to keep action opportunities open in case a particular future unfolds.

To understand when to enact those actions, the NRC could consider how to recognize how the future might be unfolding and which aspects of the future might resemble particular scenarios. This could be done through identifying a set of "signposts" i.e. precursors towards the direction of the future that reflect the broader conditions in the environment being monitored. Having identified the appropriate signposts, the NRC could then consider developing and regularly tracking a set of markers that provide clues and indications about which signposts the NRC external environment is moving toward.

These takeaways are by no means exhaustive, and as the NRC progresses towards a dynamic nuclear future, new factors could emerge that could affect how the NRC needs to accomplish its mission. The challenge will be to align the NRC's resources and process to meet mission requirements while regulating licensees in a competitive energy market and nuclear industry, in whichever futures emerge, in a manner that is timely, elevating, and does not stifle innovation.

Conclusion

This report developed four potential scenarios of the environment in which the NRC may operate in 2030 and beyond, described the implications of each scenario, and discussed key takeaways for the NRC to consider in preparation for that future environment.

It is apparent from the diversity of the scenarios that the potential nuclear futures are dynamic. These scenarios are not predictions or forecasts of the most likely futures, but narratives to stretch the NRC's thinking. Their function is to challenge conventional wisdom and help the NRC staff understand what the external environment might look like. In thinking through the possibilities for the external environment and their implications on the NRC, the scenarios guide the NRC in considering potential options for strategy, staff, expertise and skills, geographical distribution, technology, and stakeholders of the future.

The future external environment is uncertain given dynamic power demands and global innovation, but it is far from random. This report has identified several approaches and technologies, some already in use, which can enable the NRC to thrive in a range of possible futures. Agility and adaptive strategies including risk-informed and performance-based approaches to regulatory oversight will be paramount to oversee licensees in a competitive market. Attracting, developing, and retaining the right talent and knowledge in an evolving workforce will be important to support new technologies and reactor designs. Use of new tools, data analytics and cognitive technologies can help the NRC be more efficient and enable an agile workforce. Lastly, engaging increasingly diverse stakeholders, openness and transparency, and breaking a culture of risk aversion will be key to shaping a bright nuclear future.

This assessment focused on how the NRC may approach its mission in a range of possible futures. It considered how the NRC might need to transform to meet the challenges of a dynamic external environment, improve on its delivery on current and future missions, and prepare its workforce for 2030 and beyond. Through this preparation and anticipation, the NRC can pursue regulatory approaches that will ensure reasonable assurance in the protection of public health and safety, promote common defense and security, and protect the environment.

Appendix A: How Scenarios Play Out Across Time

The four scenario narratives were written to capture a moment in time in 2030. However, it is important to recognize that while the narratives were a moment in time, each scenario plays out its trajectory across time. The following tables are intended to help convey the dynamic path of each scenario.

Table 5: Nuclear Takes Off Scenario

Nuclear Takes Off		
By 2025	**In 2030**	**Beyond 2030**
Electrification of the vehicle fleet accelerates as battery technology has improved. Concerns rise about climate change and the security and reliability of the electric grid. There is a call for a long-term U.S. energy policy. Attitudes toward nuclear begin to shift among the public and investors. New health applications and isotopes are developing rapidly.	The nuclear industry grows adding new participants, new technologies and designs and new applications beyond traditional power plants. Relative economic and political attractiveness of nuclear to alternatives has improved, especially regarding gas. China, Russia, and India are innovating, investing, and internationally promoting nuclear power.	Continued growth is expected in the Unites States, especially in smaller reactors in less power-grid-centric applications. Advanced SMRs are widely deployed many in new applications. A variety of reactors using new fuel forms and cooling technologies are under construction at the same time. Experienced, skilled talent is in very short supply.

Table 6: What's Old is New Again Scenario

What's Old is New Again		
By 2025	**In 2030**	**Beyond 2030**
Advances in energy efficiency such as smart homes and LEDs, and their market adoption, have plateaued. Revitalization of the energy-intensive manufacturing sector and overall economic growth is leading to increased demand for electricity. Negative incidents surrounding fossil fuels and concerns over climate change lead to increased emphasis on clean energy. Mothballed nuclear construction sites are brought back to life. Carbon taxes or other controls are introduced at the state level.	Relative economic and political attractiveness of nuclear to alternatives has improved, particularly due to a combination of concerns over carbon emissions with an inability of renewable energy sources to meet energy demand. Energy policy decisions, again driven by climate and grid reliability concerns, favor support for nuclear energy. New LLWRs are built. Planned closures have been reversed and the majority of plants nearing the end of their licenses are applying for renewals.	The U.S. nuclear fleet continues to be strong with a mix of LLWRs and SMRs. U.S. firm designs also licensed abroad in Europe, Asia, and Africa. The greater volume and increase in demand for new nuclear plants enables economies of scale and leveraged expertise in construction processes across projects, driving down construction costs. Attracting younger workers to the nuclear industry is a challenge.

Table 7: Gone with the Wind Scenario

Gone with the Wind		
By 2025	**In 2030**	**Beyond 2030**
Energy efficiency improvements have blunted the impact of economic growth on U.S. energy demand, though global demand continues to rise. The anticipated surge in demand from electric vehicles has been offset by advances in their efficiency and effective charge utilization. Breakthroughs in battery technology are starting to resolve the intermittency problem of renewables. There is not a perceived need for nuclear power to be a significant component in any national energy policy.	Climate change is a moderate political concern and there is a booming demand in renewable energy. However, the U.S. public remains cautious of nuclear energy. Natural gas prices remain low. Groundbreaking on new nuclear reactors still occurs at a limited number of sites, but these are for SMRs which are seeing more widespread application at military sites. Overall the size of the U.S. nuclear reactor fleet has fallen steadily over the last fifteen years.	Decommissioning work and materials regulation increasingly comprise the major activities. Global economic growth and continued global demand for energy means a number of new reactors will continue to be built in the developing world, though these may be supplied by non-U.S. firms. There is a growth area for nuclear materials, however, driven by advances in the use of medical radioisotopes.

Table 8: Great Idea, But Not for U.S. Scenario

Great Idea, But Not for U.S.		
By 2025	**In 2030**	**Beyond 2030**
Energy demand in the United States has plateaued while globally energy demand is still soaring. States respond to growing public concerns over climate change by strengthening their renewable energy portfolio standards and boosting the development of renewable energy technology and investing in and/or subsidizing deployment. U.S. public acceptance of nuclear has been affected because of media attention on minor safety and security incidents. There are signs of increasing decentralization of the U.S. energy grid.	Renewable energy has become cost competitive and reached grid parity. Nuclear is viewed as relatively less economically and politically attractive compared to alternatives has improved. Reactor technology has advanced dramatically, both in terms of SMRs and advanced non-light water reactors, and the United States continues to be in the forefront of technology development. New plant construction is focused in the developing world, with U.S. firms in competition with foreign state-owned enterprises.	The distributed nature of power generation has reduced the need for large baseload sources of power in the U.S. energy grid. In the face of rising global demand and low domestic support for nuclear, the U.S. nuclear industry has pivoted away from U.S. construction toward a focus on exporting Generation IV technology and expertise internationally. A variety of reactors using new fuel forms and cooling technologies are under construction internationally.

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[1] Disclaimer: any mention of a specific company or organization is not meant to imply an endorsement on the part of the National Regulatory Commission or the U.S. Government