Transforming the U.S. Department of Energy:

Paving the Way to Commercialize Advanced Nuclear Energy

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NUCLEAR INNOVATION ALLIANCE

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This report is based on a review of relevant literature. It is also based on in-depth interviews with fifteen exceptionally well-qualified individuals and comments from expert reviewers, including former Energy Department employees or officials, reactor developers and other grant recipients, long-time contractor employees working in the trenches of nuclear energy technology development, and government scientists or academics.

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This report is available online at:
https://nuclearinnovationalliance.org/resources

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Preface

The advanced nuclear reactor technologies that are essential to a clean, reliable, affordable energy system, will not come from a garage start-up venture. They will emerge as the fruits of American industry and entrepreneurship, from a rich and complex matrix of sophisticated skills, material, fuels and other infrastructure, located in universities, National Laboratories, and a variety of businesses. These technologies will need to develop and be deployed rapidly and, in doing so, will provide greater prosperity and comfort, and position the United States as a leader in the global market. These steps are essential to address energy security, dramatically expand energy access, and achieve decarbonization.

DOE, Congress and the public need to bear in mind that some of the key tasks ahead aren't in physics or engineering, which are DOE's traditional strengths. Rather, they are in business. Success will require DOE to learn to work in step with the private sector to rebuild the supply chain and complete new projects on time and on budget. When private companies have confidence in budgets and schedules, they are more likely to invest and deploy new technologies. DOE will need to support new technologies as owners and operators learn to optimize their performance, a task that took the current generation of nuclear reactors many years to accomplish.

There are other tasks DOE will need to execute that are traditionally its strengths, but that it will need to fine-tune and execute faster. This includes coordinating with private companies in a complex industry that needs a renewed supply chain, and with other government agencies whose actions will be critical to the success of advanced nuclear technology.

The effort to move advanced reactors from the drawing board to the commercial marketplace has become even more important and timely with the turn of world events—Russia's invasion of Ukraine— in February 2022. Along with the benefits of mitigating climate change, advanced reactor success would also position the United States rather than China to fill the vacuum left by Russia's exclusion from international commerce. It is important that the United States lead internationally with exporting not only its technology, but as well its approach and commitment to nuclear non-proliferation and security, while building stronger ties with countries bilaterally.

DOE can meet these challenges, with support from the Administration, Congress and key stakeholders, and in partnerships with other government agencies and industry. But DOE also needs to transform itself.

Executive Summary

Historically, DOE has primarily been a research and development agency. More recently, emphasis is shifting toward technology deployment to meet climate and energy security challenges. In particular, DOE now has an additional task: to incubate and position innovative advanced nuclear technologies for commercialization.

Catalyzing advanced nuclear energy deployment will require a dramatic transition at optimum speed. DOE will need to coordinate across many segments of the industry as they co-evolve (as with new fuels for new reactors, for example) to allow deployment at an immense scale, and to at least double the domestic nuclear energy capacity that is online today.[1] This will be a whole-of-government and whole-of-society effort dependent on successful public-private partnerships.

The recommendations in this report provide a path for DOE to play a key role in creating the conditions necessary for success in commercializing advanced nuclear energy. These recommendations are separated into three main categories, each of which has its own chapter.

Chapter 1 recommends DOE develop a DOE-wide Advanced Nuclear Energy Strategic Plan to help commercialize advanced nuclear energy. This Strategic Plan would involve: establishing an Advanced Nuclear Energy Earthshot that integrates capabilities across DOE; leveraging recent legislation and DOE's current and future advisory committees; assessing the viable pathways to solve climate stability and energy security issues; and developing a comprehensive national strategy for exporting advanced nuclear energy technology.

Chapter 2 focuses on improvements DOE can make in its operations to assist in commercializing various advanced nuclear technologies. These improvements would require DOE to adapt to its new role as a critical partner for private companies, rather than focus solely on technical and scientific challenges, and adopt a more businesslike approach to commercialize advanced nuclear energy so that it can be deployed swiftly.

Finally, Chapter 3 recognizes that while DOE has tremendous capabilities to assist in the commercialization of advanced nuclear energy, it will face various obstacles that require help from other parts of government. To overcome these obstacles, the White House should appoint a Senior Director for Civil Nuclear Energy. Additionally, Congress should provide DOE with targeted additional funding and flexibility.

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[1] Nuclear Innovation Alliance | Fission Vision

1. Developing an Advanced Nuclear Energy Strategic Plan

Developing an overarching Advanced Nuclear Energy Strategic Plan for commercializing advanced nuclear energy is critical to meeting the nation's energy security, and clean energy goals.

Todd Allen, chairman of the Nuclear Engineering Department at the University of Michigan and former Deputy Laboratory Director for Science & Technology at the Idaho National Laboratory, made this point in testimony before the House Committee on Science, Space and Technology's nuclear subcommittee in 2021:

> "While Congress' support for nuclear energy has been strong and many new important program elements have been established, these program elements still often appear to operate independently rather than as an integrated whole." [2]

An Advanced Nuclear Energy Strategic Plan would create the organization and structure required to commercialize advanced nuclear energy. A successful Strategic Plan would be spearheaded by the Office of Nuclear Energy (NE) and would account for the interrelationship with all the nuclear-related programs at DOE – The Loan Programs Office (LPO), the Office of Clean Energy Demonstrations (OCED), the Advanced Research Projects Agency - Energy (ARPA-E), the Office of Science, the Office of Technology Transitions (OTT), and the National Laboratories, along with initiatives that cut across multiple DOE offices. This Strategic Plan would also create an integrated organizing strategy for the various nuclear energy programs, projects and technologies, including: the Advanced Reactor Demonstration Program (ARDP) demonstration projects, risk reduction awards, and advanced reactor concepts 2020; fuels initiatives; and others.

Various parts of DOE may differ on how the Strategic Plan should be organized, and such a plan is certain to require adjustments over time, because of technology breakthroughs, technology stumbling blocks, and world events. But the need to adapt or a lack of unanimity should not be a bar to having a Strategic Plan.

An Advanced Nuclear Energy Strategic Plan would be useful in any event, but it would be most useful in combination with a long-term budget plan. The Energy Act of 2020 required DOE to develop a ten-year nuclear energy budget plan, which DOE must still deliver to Congress. Such budget plans historically have not always made their way through interagency concurrence and out to Congress because providing outyear numbers, even with caveats, could be viewed as constraining the decisions of future administrations. Another challenge is that the nuclear energy programs now work independently of each other and are budgeted as such. It would be difficult for them to agree on a common long-term budget. By creating this budget plan, DOE could address the resources needed to achieve its goals and identify what the relevant DOE offices and

[2] Joint Investigations & Oversight and Energy Subcommittees Hearing – Judicious Spending to Enable Success at the Office of Nuclear Energy | Todd Allen

National Laboratories could contribute to the effort. It could lay out a plan to hire additional staff, support more technologies and awards for advanced reactors (largely under the ARDP),[3] fuels, and the nuclear supply chain through the journey to commercialization. The budget plan would have to be embedded in a broader budget plan for how DOE is allocating resources to ensure that a suite of solutions is available to meet climate and energy objectives.

***Recommendation 1-0:* DOE should develop an Advanced Nuclear Energy Strategic Plan for commercializing advanced nuclear energy.**

The following sections include recommendations on how DOE should develop this Advanced Nuclear Energy Strategic Plan.

1.1 Establish an Advanced Nuclear Energy Earthshot

DOE has organized some of its clean energy efforts around "Earthshots," a play on the "moonshot" effort of the 1960s, a national mobilization to meet a pressing goal.[4] Establishing an Advanced Nuclear Energy Earthshot would be a way to organize all of DOE's advanced nuclear energy projects under such a model. There are various ways that DOE should structure or organize an Advanced Nuclear Energy Earthshot.

The goal of an Advanced Nuclear Energy Earthshot would not simply be the development of nuclear technology, but its successful commercial deployment, so that it can be helpful in stabilizing the climate and providing reliable energy. Some factors can be influenced by the efforts of entrepreneurs and U.S. government programs, but some are profoundly affected by events around the world.

An Earthshot methodology looks at the whole supply chain. Using all the elements of DOE will support commercial developers by better integrating all DOE's existing efforts to provide advanced reactor developers with greater access to materials, tools, components and analytical capabilities that are not commercially available, or are sourced from an atrophied supply chain. Through closer coordination within DOE, an Advanced Nuclear Energy Earthshot would help better inform LPO by assisting in identifying and assessing key supply chain projects for loan guarantees. Advanced reactors also need specialized fuels that must be produced by private enterprise, and DOE has programs that can support those efforts too.[5] An Earthshot approach would focus and better coordinate DOE innovation and development efforts for the complete

[3] ARDP, which was authorized by the Energy Act of 2020, is the main vehicle for funding commercial advanced reactor demonstrations, and the Infrastructure Investment and Jobs Act added a six-year, $2.5 billion appropriation. In addition, the Inflation Reduction Act of 2022 established a production tax credit and an investment tax credit for any zero-emissions electricity producer that enters service after 2024. The Inflation Reduction Act also established a DOE program to catalyze domestic HALEU production. This combination, coming at a time of a national push for decarbonization, creates an opportunity for nuclear innovation that the technology has not seen in decades.
[4] DOE plans to announce "six to eight" Earthshots. To date, it has unveiled the Hydrogen Shot (which includes nuclear as a carbon-free source), the Long Duration Storage Shot, the Carbon Negative Shot, the Long Duration Storage Shot, the Floating Offshore Wind Shot, the Industrial Heat Shot and the Solar Shot.
[5] Idaho National Laboratory | Advanced Nuclear Fuels

fuel cycle, from the front end (which faces challenges in the transition to higher enrichments) to the back end.

DOE must ensure the Earthshot uses an organized, integrated, and cross-cutting approach. As such, DOE can integrate DOE activities across multiple offices, integrate innovation efforts from the front end through the back end of the fuel cycle, and integrate advanced reactor innovation with supply chain innovation. Among these integration efforts, proactive coordination and sharing of findings and lessons learned between the various parts of DOE so their capabilities can be leveraged is key. These parts of DOE include:

- LPO, which can share its financial expertise with other DOE offices and to help companies making reactors, fuel, and reactor components.
- The National Laboratories, which already provide help with testing and technology development individually and through the Gateway for Accelerated Innovation in Nuclear (GAIN) and the National Reactor Innovation Center (NRIC).
- OCED, the new office which now oversees the two large advanced nuclear energy demonstration projects, can do more projects and engage more with other parts of DOE and earlier-stage companies to smooth the path toward commercialization.
- ARPA-E, which often provides the resources needed to try out ideas at the component level, and for exploring concepts with an uncertain probability of success, lists four projects in the nuclear energy field.
- Office of Science, which conducts fundamental research (such as on advanced materials) and provides world-class computing capabilities.
- OTT, which serves as the central hub for transferring technology from across the DOEs extensive research and development enterprise to the private sector, and thus is already playing an important commercialization role.

Of all the DOE efforts that it needs to fully integrate, none may be as important as the National Labs. And it is not difficult to illustrate why. Each of the National Laboratories has remarkable technical capabilities. The labs tend to have strong support in Congress and are managed in a way that allows for independent scientific exploration while still adhering to congressional direction and advancing the DOE headquarters' needs. Policy experts describe congressional support for the individual labs as being far stronger than the DOE program offices, like NE, which do not reside in a single congressional district or state and do not provide high-paying jobs and economic stimulus in a concentrated way, as the National Laboratories do. To fully integrate DOE’s nuclear energy programs across the National Labs, DOE could benefit from consolidating the oversight of these National Labs’ nuclear energy work under a single manager to ensure they are coordinated and avoid overlap. Through GAIN, DOE already provides a single point of entry that helps companies navigate the bureaucracy of DOE and National Labs.

Internal coordination of the labs is also important for executing programs that support cross-cutting efforts, like hydrogen, which need to integrate advanced reactor technology with other forms of clean energy.

DOE headquarters and the National Labs already place a strong focus on the ARDP's demonstration projects, which are public-private partnerships. These partnerships are key for timely and successful commercialization of new designs. And they will advance decarbonization, energy independence, and national security.

But some DOE grant recipients report that they find it hard to navigate and access all of the technical expertise within the various DOE labs. According to a DOE grant recipient, "DOE headquarters provides no value in that. They don't view that as their job. If you get to the working level at the labs, there are a lot of really smart people, and the knowledge exchange can be really good. But it's much harder than it should be to get to that level." DOE headquarters could build on the achievements of OTT lab partnering service and GAIN's voucher program[6] by doing a better job of connecting the grant recipient with the right expert at the lab and remaining as a conduit to emphasize that the grant recipients need to have access to the labs' expertise as well as their hardware.

Another feature of the "Earthshots" is that they are aiming for clean energy generators and components that will be a success in the global market. Certainly, that should be a goal for an Advanced Nuclear Energy Earthshot, and the United States should be aiming to lead in that arena, rather than leaving the opportunity to a commercial or geo-political rival. Additionally, the Russian invasion of Ukraine has refocused U.S. attention on the importance of energy security to a stable, peaceful world. Russia's actions add urgency to the need to transform DOE to make the best use of limited resources for developing new reactor types and their domestic supply chains, to enable the American nuclear energy sector to enter the vacuum created by a new reluctance by some countries to do business with Russia. Nuclear energy designs and hardware were once a major American export, and they can be again.

***Recommendation 1-1:* DOE should establish an Advanced Nuclear Energy Earthshot that would integrate NE's capabilities with the capabilities of other parts of DOE, including OCED, ARPA-E, LPO, OTT, and DOE's National Laboratories. DOE should utilize these capabilities to support an integrated fuel cycle, advanced reactor and supply chain innovation, and to establish the United States as a global leader in advanced nuclear energy.**

[6] Idaho National Laboratory | GAIN vouchers offer new opportunities to nuclear industry developers

1.2 Focus on Cost

Cost is integral to the ability of advanced reactors to succeed in the world market, not to mention in the domestic commercial market. Nuclear energy can be priced higher than energy dependent on weather conditions because dispatchable energy is a higher-value energy product. But the size of the market share that nuclear energy occupies (and the total cost to society of a carbon-free system) will depend in part on a reactor's cost to build and operate. An Advanced Nuclear Energy Earthshot should focus on reducing the cost, to make successful commercial deployment more easily achievable.

For example, the solar and hydrogen Earthshots are both framed in terms of cost (per watt[7] and per kilogram[8], respectively). DOE should consider extending this idea to an Advanced Nuclear Energy Earthshot and should consider making cost the organizing principle as opposed to, for example, focusing only on deploying a certain number of advanced reactors or generating a specific amount of MWh of advanced nuclear energy by a predetermined date.

Nuclear energy will not fulfill its role in climate mitigation and energy security unless the actual costs of new nuclear reactor construction and operation come down. In particular, developers must be able to reliably deliver projects on budget and on schedule. In partnership with industry, DOE can be instrumental in achieving that in two ways. First, promoting best practices in project management, contracting, and oversight would enable advanced nuclear energy projects to meet schedule goals at a reasonable cost. Second, encouraging design innovations such as modularity, smaller size, higher-volume manufacturing would simplify reactor projects. For example, the standardization of certain components used in advanced reactor designs could facilitate their rapid deployment by creating a larger, predictable market for suppliers. Such innovation in standardized parts would allow multiple reactor vendors to leverage cost and supply chain benefits and would have a compounding effect on how quickly reactors can be built.

Nuclear energy does not need to be the least expensive source of energy because the kilowatt-hours it produces are a premium product that is available around the clock, all year long and in all atmospheric conditions. But nuclear energy needs to be more reasonably and predictably priced and new projects reliably delivered.

Recent industry experience offers promising results. The current fleet of nuclear energy plants set for itself a goal in 2016 of cutting operating costs by 30 percent. It was meant to be a stretch goal, aspirational, but the campaign brought forth new ideas, and the fleet met the goal by 2020. The motivation was also cost-based: to match the price of electricity from natural gas power plants.

In the construction context, the goal should be set in terms of cost per megawatt-thermal because for advanced reactors, electricity will not be the only product. The goal should be to match the

[7] Department of Energy | DOE Announces Goal to Cut Solar Costs by More than Half by 2030

[8] Mayer Brown | In Its First "Energy Earthshot," the US Department of Energy Launches Its "Hydrogen Shot" Initiative

cost of other clean firm technologies like geothermal energy, or natural gas with carbon capture. A stretch goal would be to match the cost of steam generated with natural gas without carbon capture, which is the utility industry's preferred alternative at the moment, because there is no requirement to cut climate-forcing emissions. But gas without carbon capture is not consistent with a zero-emissions economy.

Ultimately, it will be DOE's decision on how to organize its advanced reactor efforts. The Advanced Nuclear Energy Earthshot model is one logical and practical approach offered here.

***Recommendation 1-2:* DOE should focus the Advanced Nuclear Energy Earthshot on cost.**

1.3 Engage Advisory Committees

The Secretary of Energy is in the process of establishing an Industrial Technology Innovation Advisory Committee,[9,10] that should provide distinct value to DOE's effort to develop its Strategic Plan, as well as many of the needs identified in this report. The Committee is to be composed of representatives from industry, academia, independent research, and public and private entities. The Committee's purpose is to identify and evaluate emissions-reducing technologies, including nuclear energy sources to:

- Identify gaps in the available technologies being developed by the private sector or federal government.
- Identify, survey, and analyze factors that prevent the private sector's adoption of these technologies.
- Recommend technology screening criteria to encourage adoption.
- Develop a strategic plan.

The Nuclear Energy Advisory Committee is another committee that could assist DOE in developing an Advanced Nuclear Energy Strategic Plan. This committee, formerly the Nuclear Energy Research Advisory Committee, was established on October 1, 1998, to provide independent advice to the Office of Nuclear Energy (NE) on complex science and technical issues that arise in the planning, management, and implementation of DOE's nuclear energy program.

***Recommendation 1-3:* DOE should leverage its advisory committees in developing its Advanced Nuclear Energy Strategic Plan.**

[9] The Energy Act of 2020 | House Committee on Science, Space and Technology
[10] American Economic Association | DOE Industrial Technology Innovation Advisory Committee

1.4 Implement Recent Legislation

Recent legislation creates new opportunities for knitting together all the federal programs that could assist the commercialization of advanced nuclear energy.

The Inflation Reduction Act includes $700 million for DOE's Advanced Nuclear Fuel Availability Program for advanced reactors. Of that $700 million, $500 million is allocated to the production of High-Assay Low-Enriched Uranium (HALEU) for the first advanced reactors and coordination of the production and acquisition of HALEU through a consortium comprised of HALEU suppliers and advanced reactor companies. Of the $200 million remaining, $100 million will go towards designing and licensing HALEU transportation systems, and the rest ($100 million) will support other activities that assure the availability of HALEU for research, development, demonstration, and commercial use.

While winning HALEU funding in the Inflation Reduction Act is a significant accomplishment, DOE should now swiftly develop and implement a strategy to spend these funds, in accordance with the statutory deadlines. DOE must ensure that the opportunity presented by this funding is realized, and that a strong domestic supply of HALEU is available for advanced reactors. There is little room for failure. The availability of HALEU in sufficient quantities is essential to justify national investments in advanced reactors that need it.

DOE's efforts to create a strong domestic supply of HALEU must be part of a public-private partnership that will eventually be completely private. DOE is, in a sense, a catalyst for the creation of a healthy HALEU supply chain that is to be taken over by industry. As such, DOE should work with industry so that private companies can play a role in DOE's efforts, as it is beginning to do through the establishment of a HALEU consortium. The recommendations made elsewhere in this report to improve DOE's overall effectiveness will also help DOE to effectively support HALEU fuel availability for advanced reactors (e.g., adopting a more businesslike approach - as discussed in section 2.1, and hiring more staff with business qualifications – as discussed in section 2.2).

Also, while the IRA funding is critical, it is not enough. Congress also needs to provide additional appropriations, as it has begun to do with the additional $100 million in the December 2022 Omnibus spending package. Congress should provide DOE flexibility to make as efficient use of the funding as possible, for example, by creating a revolving fund that enables it to be both a buyer and a seller of HALEU.

Aside from HALEU, the Inflation Reduction Act also provides technology-neutral tax credits for production of new zero-carbon electricity. Developers can choose between an investment tax credit and a production tax credit. The amount of the credit is set according to several factors, including the project location, domestic content, and labor criteria. There is also a credit for reactors that are already running, that would be reduced or phased out if the wholesale market price of a megawatt-hour rises high enough.

The Inflation Reduction Act also opens up new possibilities in hydrogen. Tax credits of up to $3 per kilogram are available, the amount varying by timing and by the carbon footprint of the electricity source. DOE already has a pilot program operating for making hydrogen from current generation reactors but should work with reactor developers to determine how to optimize new designs for hydrogen production and for benefiting from the tax credit.

The act also raises the amount of loans available through the Loan Programs Office by $40 billion. This new loan authority is open to all eligible innovative clean energy technology categories, including projects that "retool, repower, or replace" retired energy infrastructure, which would allow loans for coal-to-nuclear projects.[11]

The hydrogen provisions in the Inflation Reduction Act complement the program emerging at DOE under the Infrastructure Investment and Jobs Act (IIJA), signed into law by President Biden in November 2021. That law calls for the establishment of "hydrogen hubs" that will work out the details of making hydrogen, from nuclear energy and other sources, and using it to displace carbon. The Infrastructure Investment and Jobs Act also provided substantial funding for ARDP.

***Recommendation 1-4:* DOE should swiftly and efficiently implement the HALEU and other programs established in IRA, and the ARDP and hydrogen funding in the IIJA.**

1.5 Develop Pathways to a Climate and Energy Security Solution

Another benefit of an integrated Advanced Nuclear Energy Strategic Plan is that it would contribute to a broader DOE effort to map out the variety of pathways to climate stability and energy security, and to get a firmer grip on what tools will be required. DOE has substantial capabilities in this area but would benefit from seeking additional input from experts in academia and the private sector.

Developing these pathways isn't something that DOE can do alone; it entails input and buy-in from other agencies. But DOE needs to drive the effort, collaborate with other agencies, and flesh out descriptions of possible pathways.

Developing climate solution pathways necessitates that DOE sketch out the entire zero-carbon landscape, including nuclear energy, sun, wind, storage, carbon capture and other clean energy technologies. It means identifying pathways to balance these tools and how to integrate them to address the future needs of society. What would an integrated energy sector look like? One that produced electricity, industrial heat, energy for district heating, and chemicals like ammonia or hydrogen that could be used as energy storage or fuel for hard-to-decarbonize aviation and heavy trucking.

[11] Loan Programs Office | Inflation Reduction Act of 2022

This is what DOE needs to sketch out, reflect in pathways and pursue those parts that seem to be essential on a system basis. Today, the tools that can help reach a solution to the climate change and energy security issues are either in hand or on the horizon. These tools, which take the shape of nuclear energy and other zero-carbon technologies, are a grab-bag of impressive concepts, some partly deployed. And this grab-bag is reflected in the messaging from policymakers who state we need an 'all-of-the-above approach.'

An integrated climate plan is not a new idea. For example, in 2016 the U.S. government produced the *United States Mid Century Strategy for Deep Decarbonization*.[12] Its detailed energy system pathways and potential strategies were developed by DOE. In November 2021, the White House issued a report, *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*,[13] which included a chapter on electricity. The plan calls for emissions-free electricity by 2035, which is twelve years from now, and would require replacing the source of approximately 60 percent of the electricity we use today with clean electricity. But it does not detail how exactly this might be done, beyond showing high-level possible combinations of generation sources.

Along these lines, LPO has already teamed up with OCED, OTT, and DOE's Office of Policy to launch the Demonstration and Deployment Pathways initiative. This initiative aims to identify what it takes to bridge the gap between demonstrations and full-scale market acceptance according to industry and investors. They have started with Clean Hydrogen, Long Duration Energy Storage, Carbon Management, and Advanced Nuclear, and kicked off productive discussions during the Business Forums at the Global Clean Energy Action Forum in September 2022.

To more precisely explore how to meet the needs of a zero-carbon economy, DOE should draw on these earlier and ongoing efforts, ensure they include the latest information on the cost and performance of technologies and fuels, and create scenarios to inform its commercialization activities.

It is not clear, for example, how much solar or wind energy a fully decarbonized system should have, and we are already seeing "curtailment" of each kind of energy in places where generation is concentrated (e.g., California for solar, and the western side of PJM for wind). Since there is no savings on operating expenses by curtailing these sources, it is clear that it is essential to add them in a coordinated way, consistent with a larger view of how much the system will require and what transmission should go along with the solar and wind farms.

A pathways assessment would inform decisions about the scale and range of reactor types that the economy will need. What is needed for industrial heat? For hydrogen production? And how will the fuel needs be met, initially and in the long term? Scenario planning should give some clues.

[12] United States Mid-Century Strategy for Deep Decarbonization
[13] The Long-Term Strategy of the United States, Pathways to Net-Zero Greenhouse Gas Emissions by 2050

Scenario planning would also make clear the magnitude of the challenge. Decarbonizing the current electricity system means retiring or capturing the carbon from nearly all of the current generation that runs on fossil fuels, which make up roughly 60 percent of U.S. electricity generation.[14] Getting carbon-emitting fuels out of highway and rail transportation, space heating and industrial use, and accommodating even modest growth in population and economic activity between now and mid-century, will mean increasing our use of electricity substantially – by as much as a factor of 2.5 to 3.[15] Fast-growing carbon-free wind and solar generation will be a major help, but these technologies are not always available. Additionally, deep decarbonization of the industrial sector, including steel, hydrogen, and ammonia production, will be essential to considering pathways to reaching climate stability and energy security. As such, mapping out pathways that include decarbonization efforts of all energy sectors is needed.

These factors mean that reaching a zero-carbon economy by mid-century will require very large additions of carbon-free energy that is dispatchable and operable as needed, regardless of weather. Only four technologies fit that profile: advanced nuclear reactors, carbon capture from fossil-fueled plants, geothermal energy, and energy storage. All three require more policy and investment to achieve commercialization at scale. In confronting a challenge as large as energy security and climate change, the likelihood of success rises when the number of potential technological solutions is increased.[16] If these challenges are met, it will only be with an integrated set of resources.

***Recommendation 1-5:* Building on earlier efforts, DOE should assess the entire zero carbon energy landscape and identify the scale and range of advanced reactor technologies that will be needed to reach our economic, security, and climate goals.**

[14] Energy Information Administration | Monthly Energy Report Table 7.21a

[15] American electricity demand has been roughly flat for the last 20 years, but globally, generation is growing by a robust 2.5 percent a year, and most of the new demand is met by burning coal, which without carbon capture is incompatible with climate goals. Demonstration of advanced reactors in the United States will clear the way for their export around the world, meeting the demands of hundreds of millions of people who have no reliable electricity today, with a carbon-free source. (See: Reuters | Global 2021 coal-fired electricity generation surges to record high)

[16] Other countries have mounted a stronger response to the challenge. China announced in November, 2021 that it would add 147 gigawatts of nuclear generating capacity by 2035, at a cost estimated at between $370 billion and $440 billion. Simply building reactors is not R&D and does not alone nurture a new technology but scaling up for a high volume of production for reactor components does lead to lower costs. In France, President Emmanuel Macron has pledged $30 billion to start replacing the entire French nuclear fleet. The country is also planning to develop a small modular reactor, primarily for export. The United Kingdom has promised $285 million to Rolls-Royce for the second phase of its SMR development, and quickly provided $133 million to keep EDF's Sizewell-C reactor on track while the company looks for private investors to replace China. China is adding reactors by the dozen while the United States is struggling to bring on a handful, but the situations are not fully comparable. For China, the imperatives include meeting ever-growing power demand, as its industrial sector continues to expand, and reducing coal shortages and choking smog from polluting coal plants. These are not issues in the United States, which has more generating capacity than it needs.

1.6 Export Success

American advanced reactors should become a tool for global decarbonization and energy security, and their export would strengthen America's economy and international influence. As the Atlantic Council pointed out in a report published in January 2020,[17] the ability of the United States to maintain safety and non-proliferation rules globally depends in part on exporting American technology. This same report noted that exporting the technology is also a strategy for addressing climate stabilization and energy security globally.

The Obama administration created an initiative for the government to be involved in supporting the export of nuclear energy technology. The project, called Team USA[18] seeks to offer a complete package to countries interested in importing U.S. nuclear energy technology, including, hardware, fuel, financing, regulatory support, and technical support. Team USA is led by the National Security Council, and seeks to achieve American non–proliferation, safety, and security standards abroad by having countries adopt American nuclear energy technology. However, Team USA has been underutilized since its inception. This should be rectified.

Although the Civil Nuclear Trade Advisory Committee (CINTAC), which advises the Secretary of Commerce, coordinates the Team USA work by bringing together all the agencies with substantive roles in civil nuclear commerce, it can revitalize its effort to better support the Team USA initiative. CINTAC is well positioned, and has the authority, to make a renewed and concerted effort to manage interagency cooperation to facilitate exporting advanced nuclear energy technology. The Committee is already composed of dozens of experts, including representatives of advanced reactor developers, companies that supply nuclear energy hardware and services, trade associations, engineering professors, government agencies, and non-governmental organizations (NGOs). With a mandate from the White House to refocus and promote civil nuclear engagement abroad, CINTAC could tackle individual trade issues, like bi-lateral nuclear energy cooperation agreements and arrange for comprehensive trade missions.

Lawmakers have proposed the International Nuclear Energy Act[19], which is an example of the type of legislation required to ensure the interagency effort that the country needs. The U.S. Department of State and other stakeholders have been engaging with lawmakers and will continue to do so in an effort to enact this or similar legislation to achieve the desired goal of facilitating export of advanced nuclear energy.

***Recommendation 1-6:* DOE should play a leading role in interagency coordination to devise and implement a comprehensive national strategy for exporting advanced nuclear energy.**

[17] Atlantic Council | International Co-financing of Nuclear Reactors Between the United States and its Allies
[18] Department of State | Geopolitics and Nuclear Energy: The View from the State Department
[19] GovTrack | S. 4064: International Nuclear Energy Act

2. Becoming More Effective in Commercializing Advanced Nuclear Energy Technologies

Apart from developing an integrated Advanced Nuclear Energy Strategic Plan, there are improvements DOE can make in its operations to assist in commercializing the nuclear technologies that will be essential to achieving DOE's climate and energy security goals.

The following sections include recommendations on how DOE can transform itself to adapt to its new role as a critical partner for private companies, rather than focusing solely on technical and scientific challenges.

2.1 Adopt a More Businesslike Approach

A businesslike approach would include carrying out tasks promptly, efficiently, without excessive bureaucratic requirements. Successful businesses are good at staffing appropriately for the tasks at hand, smoothing out contracting procedures, and recognizing that some of the ventures they will pursue will not succeed, and will turn out to be blind alleys.

DOE has often shown excellence as a technical organization, but now it needs to excel as a business incubator. That means transforming in many ways: adopting standard business procedures when negotiating non-disclosure, or intellectual property (IP) rights agreements; improving its business operations to reflect the urgency of climate challenges and the pace of the private sector; and adopting a businesslike attitude that strategically and promptly decides whether a technical approach is viable and commercially promising.

Successful private ventures try out many ideas and drop the ones that don't work. The government version, which the Energy Department should adopt, is to aim for the success of the portfolio, not *every* project in the portfolio. If there are, for example, eight key solutions to a particular problem, the important thing is that we find them, even if it takes twelve or sixteen attempts to do so.

And on the way to finding those solutions, DOE can improve its operations. According to people who do business with the DOE and some DOE officials, DOE suffers from a lack of effective IP contracts. Government contracts typically specify that if the government pays for it, the government owns the IP. But the IP is precisely what private investors want to own, and the IP in question may not be worth much to the government. DOE needs a way to address the importance for innovators to retain their rights to their IP, and in turn enable smoother contract issuance and the ability for developers to meet the aggressive deployment schedules that the government has established. Private sector investors do not generally stumble over problems like this. DOE needs a way to resolve these issues promptly, so that developers can keep to the aggressive deployment schedules that the government has laid out.

Some people involved on both sides, as contractors or as recipients of government funding, report that DOE's non-disclosure agreements likewise lack an effective and standardized approach. This is because they are negotiated on a case-by-case basis, rather than being standardized among the National Laboratories. In a field where time is of the essence, some entrepreneurs and government officials describe this process as more time-consuming and frustrating than it is in the private sector.

Improving communication between the government and the companies that government seeks to help is also essential. Government contract procedures are designed to ensure that an agency doesn't favor one private company over another. As a result, communications are often cumbersome, and while DOE needs to remain neutral until making an award, that doesn't preclude DOE from holding discussions with a prospective company, as long as it doesn't give that company an edge. According to a former DOE headquarters official working in this area, "It's remarkable how challenging it can be to get free flow interaction on what would be useful." "You're always worried about playing favorites. The idea of just picking up the phone and asking, what is the best way to do this? what do you think?' is impossible." In contrast, private sector ventures and universities may have constraints, such as competitive pressures, but retain the ability to communicate freely before a contract is signed. Successful business requires effective communication. IP agreements, non-disclosure agreements, and communication as managed now by DOE doesn't align with the private sector and, more to the point, technology innovation.

DOE, like the rest of the federal government, has a highly evolved contracting system, focused on getting the most use from each taxpayer dollar. But the system does not always appear appropriate when applied to companies pursuing innovative technologies. Compounding the need for more timely contract issuance, investors are racing to commercialize their technologies before rivals do, and in time to meet emerging needs. The government, in contrast, is more concerned with the amount spent and with following the detailed rules under government contracting processes, rather than the cost of delay. While in some situations it could make sense to prioritize traditional government procedures, this does not make sense in cases dealing with innovative technologies. These delays are not compatible with an aggressive technology deployment agenda. DOE should be handling business matters the way a business would. In developing new products, the cliche is accurate, time is money, and the object is to deploy new technologies at minimum cost to taxpayers, while recognizing that some investments will not lead to a commercial product. Additionally, delays can be expressed as parts per million of carbon dioxide added to the atmosphere.

For example, one ARDP grant awardee has found that many of the components it needs are not readily available on the commercial market, so the company is trying to internalize its supply chain. Recently, the company decided that it needed a highly specialized tool for its work, and its engineers found one that was available, albeit used, within a week or two. The company says that it is "making decisions real-time" about its needs, and when it makes a decision, it goes out to find the equipment immediately.

Pursuant to the award, DOE agreed to match the company's development costs, dollar for dollar. But under DOE rules, the government will only match the costs if the company solicits multiple bids for the equipment it needs. Even though no company could deliver the tool promptly, one company could provide a used version of the tool. That seemed expedient, since the development programs are all on accelerated schedules.

But unless the grant awardee were to put out a contract for the tool and wait for bids from other companies, the price of the tool would not be eligible for cost-sharing under the agreement. DOE leadership itself stresses the need for expeditious work, but some procedures do not allow for that. The approach of internalizing the supply chain and proceeding on an accelerated schedule simply does not work with the federal expense tracking model, the company concluded.

It is critical for DOE to modify its business operations to work with technology innovators to reach our energy security and climate goals. DOE's ability to issue funding opportunity announcements, evaluate the proposals and responses, make selections, issue contract awards, and administer them in a timely way will be critical to saving the climate. Pace is as important as scale; if DOE can't reduce delays caused by business and contracting procedures, it will make it very difficult to reach the scale of commercialization required for American society in time.

Based on the recent contract awards that DOE has issued, it is evident that DOE's process for selecting a winner and signing a contract is too slow. Even after an award winner is chosen, it still takes months until a contract is in place, money starts flowing and work can begin. "In some cases, information needs to go from NE to the Secretary's office and has to be approved before it comes out the door. It's not all NE's fault, but it's DOE's fault" said one nuclear energy scientist that has consulted with several applicants. This is one of the detriments of understaffing.

Southern Company, for example, was awarded a risk-reduction contract under ARDP, but it took another year to get a contract in place. Because climate and energy security problems are urgent, the United States needs to efficiently complete the designs of new reactors, build the prototypes, evaluate these, refine the designs, and move on to mass deployment; the nation doesn't have the time to waste on steps like writing a contract. DOE needs to streamline its internal processes wherever possible to increase efficiency and minimize challenges due to cumbersome government contracting regulations. "They don't have any appreciation for how the private sector works," said the scientist. "If they put out a funding opportunity announcement, it's a year and a half later before money starts flowing, and that's not the pace of innovation."

DOE can do better. In fact, some parts of DOE already do. DOE's GAIN has been awarding vouchers in under two months. Additionally, the two large commercial demonstration projects in ARDP were awarded within 6 months of the funding opportunity issuance, and the contracts were in place within a year after that, which is prompt for DOE, but still not fast enough. Although GAIN projects are smaller than the ARDP projects, by hiring staff with greater business acumen, it should be possible for NE to award contracts in less than six months. Additionally, certain offices within DOE, including NE and OCED, could improve their performance by adopting best practices from offices within DOE that operate swiftly.

DOE's work should be motivated by the idea that time is short to decarbonize to the extent required to mitigate global warming and strengthen energy competitiveness and security. The advanced nuclear technologies that DOE must nurture will be needed to replace as much as 60 percent of the electric system that is powered today by carbon-emitting generation, and the whole electric system will have to grow substantially - by a factor of 2 to 2.5 - if it is to replace the carbon-emitting technologies used today in transportation, space heating and industry.[20]

***Recommendation 2-1:* DOE should align with the operations of entrepreneurial businesses, and streamline, standardize, and optimize its contracting, communication, and staffing, to promptly deploy the products that are the most viable. This is essential to satisfying the urgent need for climate mitigation and energy security.**

2.2 Hire More Staff with Business Qualifications

To work well as a business incubator, DOE will need to assemble a staff with the appropriate skills and offer pay levels sufficient to recruit people out of the highly competitive private sector.

People who have worked in DOE, or in association with DOE, describe the staff that touch on the nuclear energy arena as dedicated, and skilled in many important areas, including the field of government contracting, but not so much in business skills. Their consensus view is that NE and the rest of DOE is understaffed. "The offices I deal with are short of staff and looking to hire people with experience and skills, because they just don't have them," said a former DOE official. "They've lost people, because they've been hired away, or retired or stepped out on their own." Especially lacking at DOE are people with experience in the private sector, who are familiar with business operations.

Historically, DOE and its predecessor agencies have been research and development (R&D) organizations. The U.S. energy and engineering industry has many business leaders, but they seldom go into government work; hardly anybody in the government has experience in a start-up or other entrepreneurial enterprise. "I don't have business development training, just nuclear R&D," said one former DOE official who worked there for decades in a management role. When DOE contracting rules constrain business actions, "we have nuclear R&D people making decisions on business strategy." DOE needs scientists, engineers, and, at this point, people with business expertise.

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[20] The United States consumes about 93 quadrillion BTUs of energy each year. Of that amount, the electric sector consumes about 36 quadrillion BTUs, and transportation consumes about 36 quadrillion BTUs, nearly all of which is gasoline or diesel. Decarbonizing transportation by electrifying it roughly doubles electric consumption, presuming transportation needs do not grow and require even more. Fossil fuel use in the industrial sector and for home heating would require yet more electricity to decarbonize. The upshot is an electric system that must grow by a factor of 2.5 to 3, although population growth and increasing prosperity could push consumption even higher. (Source: Energy information Administration's Monthly Energy review, Table 2.1)

DOE's shortage of personnel with experience in entrepreneurial business is not because DOE staff with this expertise has gone elsewhere; DOE never needed such expertise and therefore never sought to bring it on board. But DOE has a long history of recognizing when it needs the skills of outsiders. It is usually looking for a narrow technical skill. Now it needs to shop for business skills. "It's really important the office be fully staffed with the type of experts they need, commercial and entrepreneurial experts," said the former official.

DOE must establish a stronger pipeline for experienced professionals to join DOE in the effort to commercialize advanced nuclear reactors. A heavier emphasis on business considerations would prioritize the need for rapid decisions and for business practices that enable work at a faster pace and seek to involve private investors. And people brought into DOE to improve its business operations will understand that it may be sensible to fund ten original ideas, knowing that eight may fail but the other two will make it worthwhile. And that these investments can be smartly done by funding them as they reach predetermined performance milestones that demonstrate a project's degree of feasibility.

DOE's top leadership and the Administration need to discuss options for expanding DOE's capability to hire business expertise. The Biden Administration developed a special program, the "Day One Project Talent Hub," to help Federal agencies bring in relevant expertise, but it specifies "scientific and technical talent for focused tours of service." Widening the Hub's focus to include business expertise could be a possible solution. An expanded 'Hub' or similar program that enables DOE to focus on hiring business talent, as well as continuing to hire technical and scientific talent, would help ensure DOE is staffed with the full complement of skills it requires.

An official of DOE during the Obama administration said that in 2020, the agency is handling 50 percent more money, with roughly 30 percent less staff. From 2009 to 2020, headcount at DOE went down 7.2 percent, with an inflection point of a 3.1 percent decrease during the Trump administration, and NE was hit particularly hard.[21] DOE has only recently attempted to offset this loss, announcing in January 2022 that it will add 1,000 new staff. Success will depend on whether the pace of hiring can substantially exceed the rate at which people are leaving.

While DOE's headcount has waned, ARDP has been added to DOE's workload. In addition, OCED has taken charge of the two flagship ARDP demonstration projects, X-Energy's XE-100 and TerraPower's Natrium demonstration reactors and needs nuclear-knowledgeable government personnel to manage that. It is getting at least some of them by recruiting the expertise of NE, creating a replacement challenge there.

Additionally, there is a particular need for hiring at the National Laboratories since the pandemic began because it is costly to do. DOE staff are paid substantially less than contractors with whom they work shoulder to shoulder, about 20 percent, according to government workers. This makes hiring more difficult. In addition, some of the labs and field offices are in remote locations, like

[21] FederalPay.org | Department of Energy Salary Statistics

Idaho National Laboratory (INL), where the cost of housing has risen very substantially as a result of the pandemic.

DOE, and more broadly the whole federal government, has lost staff to retirement and competing job opportunities. People in the business and nuclear energy private sector are traditionally paid more than civil servants. But they have skills that the government will need if it is going to function as a business incubator. DOE needs pay to attract the talent it needs. There are many talented people who consider climate change and energy security the main challenges of our time, and there is an available talent pool that is inspired to do this work if DOE can recruit them.

As DOE works to hire and train new staff, it would be wise for DOE more broadly to glean lessons from ARPA-E, which has had greater success than the rest of DOE in attracting talent with business expertise through short-term positions and special hiring authorities.

***Recommendation 2-2:* DOE should hire more staff, with a focus on individuals with business expertise.**

2.3 Explore a Diverse Selection of Early-Stage Advanced Nuclear Energy Technologies

A variety of technical experts and private-sector analysts praise the virtues of a "let a thousand flowers bloom" approach. In other words, select enough baskets to put all your eggs in. That is the strategy used by ARPA-E, which is modeled after the Pentagon's highly regarded technology incubator, the Defense Advanced Research Projects Agency (DARPA), which laid the groundwork for the internet and for GPS, among other breakthroughs. The result is an audition by a wide range of technologies, and after several rounds of funding in small increments, a technology portfolio that sorts a large number of ideas according to their level of feasibility. Although individual projects may fail, the resulting portfolio is desirable, "a lot of shots on goal," as one NGO expert put it.

"The Office of Nuclear Energy could learn a lot from DARPA," said one veteran DOE contractor. "DARPA is moving at light speed with space nuclear propulsion; Department of Defense is also working with something big, Project Pele." This is a project to develop a transportable reactor in the megawatt range, to provide uninterruptible electricity for key military installations, and, eventually, to far-flung places where moving in diesel fuel is difficult.

Similarly, continuing to spread money around to early-stage concepts for civilian nuclear energy projects gives the government "a really nice universe of things to pick from," he said. "It doesn't mean that you take it across the finish line." DOE's support of new concepts during early-stage reactor development, at the component level and plant level, increases the likelihood that a greater number of viable technologies will emerge for DOE to select from for demonstrations. This is the type of DOE incubation that will produce a variety of projects to choose from, even though only some of these, those that are the most viable, will progress to commercialization.

While DOE shouldn't focus efforts on these early-stage concepts at the expense of the two large ARDP demonstrations, the continued support of these efforts is critical to the long-term success of an advanced nuclear energy portfolio.

As mentioned above, ARPA-E is another part of DOE that could help with these early-stage concepts. It is a nimble organization designed to put government money into technology ventures that are too risky for the private sector, but that have the potential to produce big results. At present, ARPA-E lists six nuclear-related projects that seem to fit that criterion: to develop special optical fibers that could monitor the core of a molten salt reactor; to develop autonomous maintenance robotic systems for molten salt reactors; to create a data-driven system for construction management; to produce advanced metallic fuel for micro-reactors; and to reduce the impacts of used nuclear fuel. (The used fuel effort is through two separate programs: Converting UNF Radioisotopes Into Energy (CURIE)[22], and Optimizing Nuclear Waste and Advanced Reactor Disposal Systems (ONWARDS)[23] program). However, in an era when multiple developers are working on new reactor types, there are certainly more projects that fall into that category.

As previously mentioned, DOE must recognize that only some of the diverse selection of early-stage advanced nuclear technologies discussed in the previous section will make it to the commercial demonstration phase, and that's okay. A recent study by the National Academy of Sciences observes that the Energy Department is supporting more technologies than will actually reach commercialization. At some point, the Energy Department will have to make decisions about which projects deserve continued support, and for that, it will need a grading system. That system will involve a combination of engineering and business considerations.[24]

The private sector recognizes the concept that successful innovation takes many tries, not all of which will succeed. This is an essential corollary to trying a broad variety of approaches; however, it requires the presumption that failure has benefits, and ensures that the surviving technologies are the best for the times. This concept is also recognized by some federal government and DOE program leaders working on technology frontiers, but it is not pervasive at DOE, and hasn't been applied yet to the effort to commercialize advanced nuclear energy. For the most part, DOE and Congress do not want to be seen investing in unsuccessful projects. Unlike private sector innovators, DOE and Congress aren't set up to recognize the value of learning from failure.

This point was made well in a letter from the Information Technology & Innovation Foundation to Secretary Granholm, on Feb. 4, 2022, and it included some useful principles. It praised investing, "in a broad swath of clean energy projects, including some that are likely to fail." In fact, according to the letter, if DOE projects show a very high success rate, that is a sign that the

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[22] ARPA-E | U.S. Department of Energy Awards $38 Million for Projects Leading Used Nuclear Fuel Recycling Initiative
[23] ARPA-E | Optimizing Nuclear Waste and Advanced Reactor Disposal Systems
[24] National Academies | Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors

program is not taking sufficient risks. If none of the DOE-backed projects fail, that could be a sign that the DOE is cherry-picking concepts that are almost certain to succeed, and that such projects could well have been carried out by the private sector unassisted. If the government only takes on winners, that means that the DOE is falling short by failing to fund higher-risk, higher-reward projects. The discovery of some dead ends is a sign that the DOE also chose some projects that will pan out, that would never have been tried by the private sector unassisted.

***Recommendation 2-3:* DOE should continue to promote early-stage design development, to germinate a wider range of technologies to select from as they mature. DOE should not fall into the trap of limiting its focus prematurely, and should utilize business principles to learn from failure and determine where additional investment should be allocated.**

2.4 Use Performance Milestones on the Road to Successful Demonstration Projects

An approach based on meeting performance milestones to support first-of-a-kind (FOAK) technologies involves applicants identifying and describing milestones that are expected to be met to continue funding. These milestones are therefore inherently linked to funding when a company reaches a milestone. Alternatively, if a milestone is not met, funding is not provided and in certain instances the project can be terminated. As discussed in NIA's milestones memo published in July,[25]

> "Milestones-based funding of demonstration projects for new energy technologies is an effective, and in many instances preferable, alternative to conventional cost reimbursement models. A Payment-for-Milestones or milestone-based approach re-imagines government support of private-sector innovation, tying funds to the achievement of specific hardware, technical, and/or financial milestones."

In this report, NIA also noted the following:

> "Unlike cooperative agreements, which are designed for R&D, milestone-based approaches are well suited to bridging the commercialization valley of death, balancing risks between the public and private sector. Such an approach would set up a simpler and more flexible system for companies looking to demonstrate the successful deployment of their technology. By awarding funding to a company when they achieve specific commercial milestones, this model incentivizes more rapid innovation and can provide off ramps for federal funding of projects that initial work makes clear are not likely to succeed. Funding using a milestones-based approach reduces taxpayer risk, reduces project performance risks, and can accelerate commercialization. Ultimately, such

[25] Nuclear Innovation Alliance | Memo on Milestones Approach to Advanced Reactor Demonstration Projects

approaches encourage DOE to adopt an investor mindset for demonstration projects, as opposed to funding them as applied research."

Milestones also help determine the degree to which projects are on schedule. While schedules are important, DOE needs to allow for adjustments along the way, and a milestone-based approach accounts for this.

DOE needs to implement a flexible milestone approach to adjust to a developer's need to effectively deal with technological bumps in the road. Completing viable reactor designs is integral to addressing the climate challenge, so allowing companies to set tangible milestones and giving them the flexibility to reach these pre-established milestones through whatever means suit them best, is the best approach to swiftly commercialize advanced nuclear energy.[26]

The Energy Department also needs milestones to determine what is working. Ambitious FOAK demonstration projects are challenging to pull off successfully. They require careful management and adjustment based on progress with respect to performance milestones. As such, evaluating progress through pre-determined milestones will give DOE the opportunity to properly consider whether and how to continue with a project.

***Recommendation 2-4:* DOE should fund projects contingent on their progress, by setting payments based on achievement of technical and economic milestones. DOE should continuously evaluate the projects it is funding, adjusting payments and schedules where warranted.**

2.5 Assist with the Transition from Demonstration Projects to Full Commercialization

As new reactor types work their way up the reliability curve, DOE will need to provide support, even after demonstration reactors are built, if it wants to ensure the success of these technologies. The public investment in these projects justifies a follow-through until they approach operational maturity. Nurturing a new technology until it becomes profitable is an important aspect of standard business behavior that the country needs to adopt for advanced nuclear energy.

This principle is not unique to advanced nuclear energy. Innovative technologies in every sector often take several project iterations and adjustments before they perform well and reliably. This isn't new or surprising, but it's often forgotten. Take, for example, hybrid gasoline-electric cars, now ubiquitous on American roads. The Toyota Prius, one of the first two commercial entries in

[26] There are examples of DOE investments that failed because DOE lacked the flexibility to acknowledge emerging challenges promptly and take corrective action to avoid the failure. The Clinch River Breeder Reactor was canceled in the early 1980s after $1.7 billion was spent; the Synthetic Fuels Corporation was canceled in 1986 after $2 billion was spent; and the Superconducting Supercollider ended in 1993 after $2 billion had been spent. In each case, the government might have benefited from using milestones. Missing those milestones might have prompted managers to cut their losses or adjust along the way, exploring details before adhering to a program for which the original budget and schedule are determined to be no longer feasible.

the category, sold barely 5,000 units in its first year, a number far smaller than could justify its development costs. Toyota took losses for years, and then eventually sold hundreds of thousands a year, and paved the way for other hybrid models.[27]

There are examples from history that demonstrate how early investments in FOAK reactors were lost because a lack of financial resources early in the reactor's operation made it too difficult to make the adjustments necessary to perfect the technology. Ft. St. Vrain, an early gas-graphite reactor, was retired by its owners because working the bugs out of the new design and making it run reliably was more expensive than the power company's alternative, going back to burning coal. Likewise, another early reactor design, Fermi 1, a breeder reactor cooled by liquid sodium, did not perform well in its early years. To compensate for financial losses, its owners added an oil burner, to make use of the turbine-generator when the reactor wasn't running. The owners found it cheaper to scrap the technology than to optimize what they had. In the St. Vrain and Fermi cases, if government had recognized a public benefit to extending support to a technology with a shaky start, we might have commercialized these two technologies decades ago, which would have been of minor benefit to the owners and major benefit to the public, the definition of a case where government intervention is a good idea.

Likewise, the light water reactors that today run more than 90 percent of the hours in a year used to operate only half the hours in a year.[28] If those light water reactors were first being introduced today, they would face a much more difficult financial environment, with pressures to close plants that did not show high reliability early on, as today's now-reliable reactors did not in their early years. But growing expertise of the operators turned shaky new entrants into the high-performing workhorses of the electricity generating system.

When light water reactors were introduced, the plant owners were vertically integrated companies regulated by public service commissions, which could take a longer view and accept short-term losses on a fledgling plant.

DOE should continue to nurture advanced nuclear technologies, because initial operating experience, even if sub-optimal, is valuable, and will lead to follow-on units that will operate better, as well as be less expensive to build. The technology will be competitive when it reaches "nth-of-a-kind" units, which can flourish even in a deregulated market. But there needs to be a clearer path for how the technologies will reach that point, and a recognition that government support may be required to get there.

There are a variety of mechanisms. Among them: Government can be a hardware buyer for early versions of a product (as it was for the Wright Brothers), a services buyer (as it is now for energy from solar and wind farms), or a source of loan guarantees (as it is for various clean energy projects including nuclear energy).

[27] Green Car Reports | Toyota Prius hybrid sales have tanked: here are 4 reasons why
[28] Nuclear Energy Institute | U.S. Nuclear Generating Statistics

Recommendation 2-5: ***DOE should help demonstration projects to bridge the gap between initial deployment and full commercialization and ensure that the companies building these technologies have the resources needed to achieve competitive success.***

2.6 Help Nuclear Startups Pay Government Licensing Fees

Making the leap beyond the traditional light water designs now in use, and commercializing a new reactor type will be difficult, because of what the economists call "barriers to entry": the high start-up cost, the technical complexity and the problem of overcoming industrial inertia. The inertia is in the industrial base: once the design strays from light water and from low-enriched ceramic uranium fuel pellets loaded into a metal fuel rod, then thousands of new components are needed, components that are not now commercially available.

Companies face challenges crossing that peculiar feature of capitalism, which is known as the "valley of death," the gap between what they can design, and possibly even prototype, and a commercial product. Among the complications, a commercial version of a new technology has to be manufactured and sold in a time period and at a scale that allows costs to drop enough to assure success. And in machines as complicated as nuclear reactors, the prototypes or first commercial editions may show poor reliability. This was certainly initially true of the now highly reliable light water reactor designs in service.

Government can play a variety of roles to assist emerging advanced technologies, and DOE can facilitate these transactions. One unusual problem for nuclear energy is the cost of licensing a new design, or obtaining a reactor operating license. The costs to license a nuclear reactor is paid directly and in full by the applicant to the Nuclear Regulatory Commission (NRC), and licensing work for reviewing the applications is billed to the private sector at more than $290 per staff hour. In contrast, in the aviation field, the costs incurred by the Federal Aviation Administration to certify a new aircraft are paid with public funds, through taxes on airline tickets, cargo waybills and jet fuel. Most of the Food and Drug Administration's costs are also paid by taxpayers.

High licensing costs for nuclear reactors (often tens of millions of dollars) were historically supported by large companies, but now small startups are working to develop and license new technologies. These additional regulatory costs could be a barrier for small, privately funded advanced reactor startups. Therefore, the high cost of licensing inhibits private sector innovation and DOE's efforts to commercialize the technologies

Additionally, when utilities and private companies seek operating licenses for new reactors, they will also be responsible for paying similarly high licensing costs. These costs could be passed directly to rate payers under regulated utility models but could be an impediment for merchant electric companies or other small non-utility energy customers interested deploying new nuclear energy.

In 2017, Congress authorized a program for DOE to share applicants' licensing fees, under the Nuclear Energy Innovation Capabilities Act. In August 2022, the Senate Appropriations Committee proposed to appropriate $5 million for the program to start accepting applicants and program funding was included in the December 2022 Omnibus spending package. This appropriation is an excellent start, and DOE should implement it strategically and expeditiously. But it only begins to address the need for public funding to support the high costs of nuclear reactor licensing under the NRC's current fee model.

DOE can also help advanced reactor licensing by providing technical assistance to companies preparing advanced reactor license applications and increasing engagement with the NRC to help inform updates to its licensing process for advanced reactors. DOE technical support of advanced reactor license applicants can leverage existing DOE expertise to help applicants create high-quality technical applications for advanced reactor licenses. Additionally, DOE can provide technical input to the NRC to help inform changes to existing regulation (e.g., 10 CFR Parts 50 and 52) and development of new regulation (e.g., 10 CFR Part 53) to help ensure that the final NRC rules enable effective and efficient licensing. DOE should also engage with NRC as it is focusing on addressing rulemakings for licensing advanced reactor technologies, while maintaining NRC's independence.

This is particularly important because the nuclear energy industry is among the most high-tech of American industries and placing the full licensing burden on the regulated companies is incompatible with sustaining innovation necessary for the industry to thrive. The cost of certifying new models for nuclear energy should follow the pattern used for airplanes, cars and other equipment: the money should come from general treasury revenues or fees on consumers.

***Recommendation 2-6:* DOE should reduce the innovation barrier faced by start-ups seeking NRC licenses by funding their licensing fees.**

2.7 Build a Fast Neutron Testing Capability

Either through a new fast neutron test reactor, or some other means, developers of advanced reactors will need to be able to test components in a neutron flux similar to what would be present in in the advanced reactor itself.

DOE could support advanced reactor commercialization by moving ahead with a fast neutron test reactor, a device that can simulate many years of wear and tear on components. While DOE has test reactors that use thermal neutrons (i.e., low-energy neutrons that move at much slower speeds compared to higher-energy fast neutrons), a fast neutron test reactor would be able to bombard samples with a spectrum of fast neutrons that more closely resemble what the components would see in an actual fast reactor. Therefore, this test facility would irradiate the components with a very high rate of neutron bombardment in a short period of time to simulate damage that would typically take years to occur. Reactor cores are a harsh environment, where heat, chemicals, and radiation in various forms combine to degrade fuel elements and structural components. A reactor designer would like to be certain that fuel and structural components will last at least as long as their scheduled time in the reactor. Therefore, a fast neutron test reactor can provide invaluable information on the behavior of these components. Additionally, a fast neutron test reactor can also help develop the instrumentation and sensors for advanced reactors. And it can do work relevant to new designs and existing plants, accident-tolerant fuel, and validating other new fuel types.

Just as the government has built wind tunnels for airplanes, test tracks for new railroad locomotives, or launch pads for privately built space rockets, DOE has opened test beds at NRIC for FOAK reactors. DOE should also build a fast neutron test reactor to test materials and components. The government provides testing capability for high-tech industries because the function is one that all of the companies in the sector benefit from, yet it isn't logical or feasible for each one to create its own testing capability. As such, only the government has the means and the incentive to build a fast neutron test reactor that benefits all of society, not just a single company.

Although thermal test reactors can't simulate the same degree of materials degradation as a fast neutron reactor in the same amount of time, they still provide useful data and information. However, the United States, with aspirations to advance a new generation of nuclear energy technology, has failed to replace aging thermal test reactors. Compounding this, the same is true for countries throughout the western world. As a result, the current nuclear research infrastructure vital for testing components for advanced reactors has declined sharply in the last few years. For example, the Halden reactor in Norway was 60 years old when it was retired, and developers of Accident Tolerant Fuel had been planning to use it for testing. The National Research Universal reactor, better known as NRU, at Chalk River, in Ontario, built to irradiate entire fuel assemblies, was retired in 2018 after its reactor vessel became corroded and began leaking heavy water. Although the Advanced Test Reactor in Idaho is still operating, its capacity is largely used by the U.S. Navy for testing components for propulsion reactors and for testing Accident Tolerant Fuel.[29]

For a time, it was possible to send samples to be irradiated by fast neutrons in Russia because the Russians already have a reactor that can provide fast neutrons for test purposes. And Russia is building another, the MBIR, which Rosatom describes as a multipurpose fast neutron research facility, for testing new fuels and coolants. One U.S. nuclear energy company, Lightbridge, even sent samples for irradiation in Russia, a process that was cumbersome at the time, and since the Russian invasion of Ukraine, impossible.

We can build advanced reactors with materials that have not been thoroughly tested, but it increases commercial risk. Key components could turn out to be more brittle than expected after a few years of use, or subject to some form of corrosion that is not now recognized. A lack of fast neutron testing capability could create designs that will prove after a few years of operation

[29] Accident Tolerant Fuel is a refinement of the standard fuel for light-water reactors, uranium in ceramic pellets with a cladding of a zirconium alloy. ATF is coated or doped with other materials so that if cooling is lost, it will maintain its shape and strength for a longer period.

to have been bad choices, and the only way to definitively resolve this is to find testing solutions domestically or with our allies.[30]

***Recommendation 2-7:* DOE should establish a fast neutron testing capability to support future generations of reactor technology.**

2.8 Ensure a Robust Supply Chain

Beyond fuel, DOE does not seem to have any integrated effort to support common supply-chain needs for advanced reactors. In fact, DOE generally does not have experience in supporting supply domestic supply chains, because as discussed in previous sections, DOE is primarily an R&D organization. A more robust supply chain would reduce the cost and shorten the time for building new reactors, making them more attractive to utilities. Better supply chains could also make reactors more attractive to non-utility customers, like carbon-intensive industries that need large amounts of process heat.

The help could take many forms. For example, various kinds of reactors could use better heat exchangers. But it would take a government program to encourage the development of a supply chain for novel equipment that has not yet been commercially demonstrated. As with the suppliers of nuclear fuel, the suppliers (or potential suppliers) of these components for advanced reactors are reluctant to make big investments to support a technology that may never be widely deployed. Pumps and valves for molten salt may be in the same category.

"What I'd like to see is looking at sub concept-level issues," said one former DOE official now in the private sector. Areas ripe for this approach, he said, were fuel handling, reactivity control, pumps and valves, and different materials for pressure vessels and piping. Additive manufacturing, more widely known as 3D printing, is another area that should receive more DOE attention as part of the effort to improve the supply chain. "The sub system-level stuff deserves to be a focus for innovation," he said.

DOE does recognize the supply chain problem. A recent DOE report[31] on supply chain issues for all forms of clean energy pointed to deficiencies in domestic manufacturing and fabrication facilities for advanced nuclear technologies and fuels and the reluctance of the private sector to tool up for technologies that may not reach commercialization. The report proposed a variety of remedies, including promptly licensing some advanced technologies, and building the Versatile Test Reactor or some other fast-neutron test facility. Encouraging exports of nuclear technology would also broaden the market, the report said.

There have been other proposals to bolster the supply chain for the clean energy industry as a whole. Southern Company, for example, proposed that DOE fund a research hub for salt, where

[30] White House | FACT SHEET: President Biden Signs Executive Order Catalyzing America's Clean Energy Economy Through Federal Sustainability

[31] Department of Energy | America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition

users could test their designs. The users could have been any developer, nuclear or non-nuclear, planning to use molten salt as a coolant or heat transfer fluid. The salt hub would be partially modeled after the carbon capture hub at the National Energy Technology Laboratory (NETL), part of DOE.

The proposed salt hub would have been a non-nuclear facility with heated salt available to a variety of users for experimental work, minimizing the time and expense required to demonstrate valves, pumps and other components, and to explore the characteristics of fluorides and chlorides. DOE did not accept Southern Company's idea, although it has not detailed why.

Another step DOE should take to encourage the supply chain is to provide greater access to knowledge resources. Convene workshops or working groups, perhaps in partnership with the American Society of Mechanical Engineers, the Electric Power Research Institute, and the Institute of Electrical and Electronic Engineers, to explore what companies can be drawn into the industry, and what certifications and standards would apply. Vogtle suffered tremendous cost overruns and delays caused, in part, by inexperienced component suppliers that did not understand requirements for documentation, certification, and quality for parts used in nuclear energy plants. Rework and corrections to component quality issues and resulting supply chain bottlenecks created cascading schedules and cost overruns. It is important to note that these challenges occurred for a reactor design that was largely based on existing reactors and used conventional fuel, moderator and control systems.

DOE should also support industry collaboration on the development and production of standardized common components or materials that could be used in multiple different reactor designs. Collaborative development of components such as pumps and valves, or development and qualification of nuclear fuels and structural materials should spread the development cost across multiple companies and reduce risk for suppliers as there are multiple future buyers. Federal support for these standardized components or materials would improve the domestic supply chain and help American component suppliers compete in the international market.

And an industry shift to smaller reactors implies a reliance on smaller components, including reactor vessels, pumps and heat exchangers. These components should be produced by a wider variety of fabricators and increase opportunities for domestic manufacturers. But as the Vogtle example shows, suppliers who are new to the industry may not initially produce components that meet strict quality or documentation requirements.[32] Expanding the base of nuclear energy suppliers will make the supply chain more robust but may require work to ensure that new entrants understand the requirements of the business that they are joining.

LPO is in a unique position to contribute to the build-out of the supply chain. The Energy Act of 2020 gives the LPO the ability to provide financing to the nuclear energy supply chain, including the Energy Infrastructure Reinvestment Program that provides loan guarantees to projects that retool, repower, repurpose, or replace energy infrastructure that has ceased operations. "That's a

[32] S&P Global Commodity Insights | US NRC says site making nuclear reactor parts has safety issues

big opportunity," said one NGO expert. And it is encouraging that DOE is taking steps to update the policies and processes for LPO's Innovative Technologies Loan Guarantee Program, which has been well-resourced to provide guarantees for advanced nuclear energy projects, with a specific carve-out for the supply chain.[33] DOE will need to continue to coordinate with LPO and ensure that LPO works closely with applicants and related entities. As LPO reviews specific technologies, DOE can also monitor that LPO is working with OCED, NE, and the National Labs to obtain technical insight. Also, LPO should not be constrained in offering loans to companies receiving DOE assistance.

Jigar Shah, the head of the LPO, said in a recent podcast that the program was "agnostic" about whether to invest in renewables, nuclear energy or even fossil fuels if it cut carbon emissions. The program's purpose, he said, is to foster innovation by "helping technologies that are misunderstood by the commercial debt markets," and "if we get a whole bunch of nuclear applications, that money will go there,'' he said.[34] As such, an area ripe for intervention by LPO is the supply chain.

***Recommendation 2-8:* DOE should launch an integrated effort to support common supply-chain needs for advanced reactors through, for example, innovation hubs and LPO loans. DOE should canvass the advanced reactor community to identify common components or materials that could be standardized for development and production, develop estimates of market size, and determine what incentives the private sector would need to certify and produce the components.**

3. Integrating Advanced Nuclear Energy Efforts Across the Federal Government

While DOE has tremendous capabilities to assist in commercializing advanced nuclear energy, other parts of government will need to help. The whole government, including Congress, needs to have a sense of urgency. Many of the recommendations in this report will require efforts at other agencies or targeted additional funding or flexibility from Congress. The following sections include recommendations for the federal government more broadly.

3.1 Create a Leadership Structure Appropriate to an Interdepartmental Approach

A challenge for incubating, launching and deploying a new generation of advanced reactors is that so much of the work lies outside the purview of the Department of Energy's energy programs, or, at least, needs the buy-in from other organizations. These include the departments

[33] Loan Programs Office | Financing Options for Energy Infrastructure
[34] COWEN | Nuclear Power with DOE Loan Director Jigar Shah

of Commerce, State, Defense and Homeland Security; the National Nuclear Security Administration[35] (the semi-autonomous nuclear defense office within the Department of Energy), the International Development Finance Corporation and the Export-Import Bank of the United States, and some White House agencies, including the Office of Science and Technology Policy, and the Office of Management and Budget (OMB). It will also involve the Nuclear Regulatory Commission, consistent with that agency maintaining its independence.

One approach to solving these problems would be to put somebody in charge. That is the way that the government has approached other pressing problems, and deployment of a new generation of advanced reactors requires this same degree of commitment, to address climate, clean air, energy security and national prosperity.

The Biden administration has "Czars" for drug control, Covid-19, supply chain, and climate. In the past we've also had czars for energy, Ebola, AIDS, terrorism, urban affairs and human trafficking. Very few had "Czar" in the official title; more often, they are called directors or administrators. For this job, a Senior Director for Civil Nuclear Energy would fit, and such a person could sensibly be made a member of the National Security Council, a White House agency. In fact, the White House previously had such a position during the Obama administration, when the National Security Council had a Director for Nuclear Energy Policy. Appointment of such a senior figure would be a step toward assuring the required coordination. They would especially be useful to coordinate an Administration-wide effort exporting advanced nuclear energy technologies.

While this report's recommendations are primarily for DOE, accomplishing some of them will require actions by other entities, including OMB, which is responsible for approving most budget requests. One challenge is winning OMB approval for a long-term advanced nuclear energy budget plan, and this person in charge could be instrumental in making that happen. Appointing a Senior Director for Civil Nuclear Energy at the White House would help with this effort.

***Recommendation 3-1:* The Administration should appoint a Senior Director for Civil Nuclear Energy at the White House to coordinate among all the government entities needed for the successful deployment of a new generation of nuclear reactors.**

[35] Established by Congress in 2000, NNSA is a semi-autonomous agency within the U.S. Department of Energy responsible for enhancing national security through the military application of nuclear science. NNSA maintains and enhances the safety, security, and effectiveness of the U.S. nuclear weapons stockpile; works to reduce the global danger from weapons of mass destruction; provides the U.S. Navy with safe and militarily effective nuclear propulsion; and responds to nuclear and radiological emergencies in the United States and abroad. (See: Energy.Gov | About NNSA)

3.2 Additional Funding and Flexibility from Congress

While this report is primarily focused on DOE implementation of programs recently authorized and appropriated, several recommendations herein may require additional funding and flexibility from Congress.

For example, as discussed in section 1.4, Congress must provide additional HALEU funding through DOE's advanced nuclear fuel availability program. While the IRA funding is critical, it is not enough to catalyze a domestic commercial HALEU market. Congress needs to provide additional appropriations to support program operation, as it has begun to do with the additional $100 million in the December 2022 Omnibus spending package. Congress should provide DOE flexibility to make as efficient use of the funding as possible, for example by creating a revolving fund that enables it to be both a buyer and a seller of HALEU.

As another example, as discussed in section 2.7, a fast neutron test reactor would make it easier to build advanced reactors, by allowing for the irradiation of fuels and components for fast reactors to ensure they can maintain their durability during the many years they are in service. DOE has been pursuing a proposal for the Versatile Test Reactor (VTR), a fast neutron test reactor that would have been built at INL. However, as the funding bill for the fiscal year beginning Oct. 1, 2022, made its way through Congress, despite a high level of funding for nuclear projects, the VTR received no funding, and it has continued to receive no funding. In light of this lack of support, DOE should make a better case for the VTR, or come up with alternative approaches to fast neutron testing (e.g., through international collaboration or at commercial facilities that might be adapted for these test purposes).

As discussed in section 2.2, DOE needs to pay well to attract the talent it needs to help commercialize advanced nuclear energy, mainly because DOE is losing staff to retirement and competing job opportunities, and because they need to attract qualified professionals, especially those with business experience, away from the private sector. DOE and the Office of Personnel Management (an office that that provides personnel management leadership across federal agencies[36]) already has rules allowing for higher pay for highly qualified individuals who fill the special needs of federal agencies.[37] DOE may need money or additional flexibility from Congress to fully take advantage of such authorities. Additionally, the staffing level at NE is determined by specific federal budget requests and congressional appropriations. As such, Congress should ensure DOE has the tools to attract the workforce needed to commercialize advanced nuclear energy.

***Recommendation 3-2:* Congress should support DOE efforts to implement the HALEU fuel availability program, develop fast neutron testing capability, and hire more staff through targeted additional funding and flexibility.**

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[36] Office of Personnel Management

[37] U.S. Office of Personnel Management | Fact Sheet: Superior Qualifications and Special Needs Pay-Setting Authority

Conclusion

If the United States is going to address climate change and energy security, it will be because the country has harnessed advanced nuclear energy, along with other clean energy technologies, to produce plentiful, reliable and affordable carbon-free energy. That will require an organized, efficient, and well-funded DOE. A business-minded DOE will have to provide the infrastructure tools required, and the resources to jump start this new industry.

This report addresses how to create an effective interface between government and business, to drive the clean energy economy, and, specifically, to commercialize advanced nuclear energy. For this collaboration to be successful, the two sides will need to work together seamlessly through extensive public-private partnerships, to harness the creativity and productivity of industry, to meet public goals. As with any high-tech innovation, advanced nuclear energy will perform better over time. But private business won't make the leap required without an initial research, development, demonstration and deployment push from the government.

The entrepreneurial culture of the emerging advanced nuclear energy industry is an American strength. But as has been the case for all successful U.S. energy technologies, it needs a well-suited federal partner. The government should provide public support because the entrepreneur's final product will meet needs for the whole country, or even the whole world. These are extensive benefits that will not flow through to the bottom line of profit-making corporations. These include stabilizing the climate, improving America's competitive position worldwide, increasing energy security, and eliminating the air pollutants from fossil fuel use.

As the world grapples with the challenge of climate change and energy security, and the government seeks to nudge the behemoth of the energy-using economy towards a zero-carbon path, it is obvious that we need technology innovation, a gift that DOE has long given. But we need commercialization, too. And for that we need DOE to transform itself into a better partner for industry and society as a whole.

Summary of Recommendations

Chapter 1: Developing an Advanced Nuclear Energy Strategic Plan

1-0. DOE should develop an Advanced Nuclear Energy Strategic Plan for commercializing advanced nuclear energy.

1-1. DOE should establish an Advanced Nuclear Energy Earthshot that would integrate NE's capabilities with the capabilities of other parts of DOE, including OCED, ARPA-E, LPO, OTT, and DOE's National Laboratories. DOE should utilize these capabilities to support integrated fuel cycle, advanced reactor and supply chain innovation, and to establish the United States as a global leader in advanced nuclear energy.

1-2. DOE should focus the Advanced Nuclear Energy Earthshot on cost.

1-3. DOE should leverage its advisory committees in developing its Advanced Nuclear Energy Strategic Plan.

1-4. DOE swiftly and efficiently implement the HALEU and other programs established in IRA, and the ARDP and hydrogen funding in the IIJA.

1-5. Building on earlier efforts, DOE should assess the entire zero carbon energy landscape and identify the scale and range of advanced reactor technologies that will be needed to reach our economic, security, and climate goals.

1-6. DOE should play a leading role in interagency coordination to devise and implement a comprehensive national strategy for exporting advanced nuclear energy.

Chapter 2: Becoming More Effective in Commercializing Advanced Nuclear Energy Technologies

2-1. DOE should align with the operations of entrepreneurial businesses, and streamline, standardize, and optimize its contracting, communication, and staffing, to promptly deploy the products that are the most viable. This is essential to satisfying the urgent need for climate mitigation and energy security.

2-2. DOE should hire more staff, with a focus on individuals with business expertise.

2-3. DOE should continue to promote early-stage design development, to germinate a wider range of technologies to select from as they mature. DOE should not fall into the trap of limiting its focus prematurely, and should utilize business principles to learn from failure and determine where additional investment should be allocated.

2-4. DOE should fund projects contingent on their progress, by setting payments based on achievement of technical and economic milestones. DOE should continuously evaluate the projects it is funding, adjusting payments and schedules where warranted.

2-5. DOE should help demonstration projects to bridge the gap between initial deployment and full commercialization and ensure that the companies building these technologies have the resources needed to achieve competitive success.

2-6. DOE should reduce the innovation barrier faced by start-ups seeking NRC licenses by funding their licensing fees.

2-7. DOE should establish a fast neutron testing capability to support future generations of reactor technology.

2-8. DOE should launch an integrated effort to support common supply-chain needs for advanced reactors through, for example, innovation hubs and LPO loans. DOE should canvass the advanced reactor community to identify common components or materials that could be standardized for development and production, develop estimates of market size, and determine what incentives the private sector would need to certify and produce the components.

Chapter 3: Integrating Advanced Nuclear Energy Efforts Across the Federal Government

3-1. The Administration should appoint a Senior Director for Civil Nuclear Energy at the White House to coordinate among all the government entities needed for the successful deployment of a new generation of nuclear reactors.

3-2. Congress should support DOE efforts to implement the HALEU fuel availability program, develop fast neutron testing capability, and hire more staff through targeted additional funding and flexibility.