COMMENTS & RECOMMENDATIONS FROM THE NEAC INFRASTRUCTURE SUBCOMMITTEE

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The mix of resources utilized to produce electricity in the United States is changing dramatically given the national and worldwide move toward decarbonization and need for energy security. Nuclear energy will play a significant role in this evolution given its carbon-free characteristics and the reliability with which it operates. Multiple studies summarized for the Subcommittee by the Loan Programs Office indicate that as much as 200GW of new nuclear will be required to support net zero carbon emissions in the U.S. by 2050. Short, mid and long-term priorities for the Office of Nuclear Energy (NE) should therefore be focused on commercialization of nuclear technologies both to add to the existing nuclear fleet (recognizing the timeframe necessary to build new nuclear), and also to prepare for replacing nuclear generation assets with advanced technology.

The Infrastructure Subcommittee was formed under the Nuclear Energy Advisory Committee for the purpose of formulating recommendations to the Committee and NE regarding priorities for time and funding investment. The Subcommittee met on numerous occasions in 2022 and 2023 and received presentations from Alice Caponiti (DAS, NE-5), overview of the President's budget proposal by Patrick Edgerton, as well as a presentation from Julie Kozeracki and Christopher Vlahoplus from DOE's Loan Programs Office to form the basis of the below recommendations. At the conclusion of these recommendations, we also indicate potential areas for further investigation by the Subcommittee should the Committee decide to continue its charge.

The Subcommittee notes at the outset that physical infrastructure is a very broad topic. There are infrastructure issues associated with:

- Workforce development (tie between intellectual and physical infrastructure)
- Continuous innovation (R&D infrastructure mostly at the universities and national laboratories)
- Demonstration of advanced concepts (public-private partnerships)
- Large-scale commercialization (private investments enabled by loan and tax policies)

Trying to comprehensively cover all these different aspects would dilute our effort and the Subcommittee is concerned that may not be very beneficial to NE in terms of actionable recommendations. As such the Subcommittee presents the below list of recommendations in an effort to maintain a scope that will be useful to NE.

General

1) **NE should develop an effective narrative around the need for and benefits of nuclear energy given the worldwide efforts to decarbonize and the global need for energy security. The narrative should acknowledge the pressing needs associated with combating climate change and addressing energy justice in the near term and also sustain those efforts well beyond 2050.**

The narrative (mission need) for any new major infrastructure investment must be developed carefully. The time-scale necessary to develop new infrastructure to the point of providing useful results makes it difficult to argue for their use to meet 2030-2050 GHG emission reductions (especially true for technology requiring supporting innovation infrastructure that does not exist today). This is a long-term effort, and the strategy should be equally forward-looking and reviewed regularly. There should be a near/mid/long profile established - with an emphasis of what will be changing across the technology and the market.

2) **NE should develop an infrastructure strategy that is focused on achieving established priorities, the most important of which is accelerating commercial deployment of existing reactor technology and advanced reactor technology. The strategy should include a clear indication on expected benefits, and milestones to be achieved in the near-term and long-term.**

Under the NE program, infrastructure investments are made in different offices. NE-4 focuses on INL infrastructure. NE-4 and NE-5 also are making investments directly supporting the R&D programs that they manage. NRIC under NE-5 appears to be investing considerable funding to support demonstration projects exclusively focusing on micro-reactors (or even much smaller critical facilities aimed at fundamental research, e.g., ~200 kW salt loop in an INL hot cell). How well these needs are integrated under an overall strategy considering the national priorities with an appropriate timeline was not clear in the presentations. While there are certainly some internal deliberations on these topics, the basis for the choices is not clear to outside observers, thus making it difficult to assess its sustainability.

Short-term: 5-Year Focus

3) **Highest priority focus in the near term is moving forward expeditiously on getting more nuclear capability into commercial operation through demo projects utilizing existing technology. Longer term these issues tie to integration into industrial use cases, which may require new facilities for systems testing.**

The Subcommittee recommends that NE's focus in the relatively near term should be on minor modifications to existing infrastructure to support LWR (or LWR-based SMR) deployment. Infrastructure sufficient to support the high-priority Accident Tolerant Fuel program for LWRs, along with other infrastructure needs to support these deployments.

Mid-term and Long-term

4) **The recent report from National Academy of Engineering and the DOE Pathways to Commercial Liftoff report [1],[2] recommended a focus on materials development, construction technology R&D and workforce development. In the context of these areas, infrastructure is needed to support materials and construction R&D and certainly university training infrastructure to build workforce could be an area of emphasis. As a committee we continue to recommend focus on these areas.**

The nuclear infrastructure needs related to these focus areas may overlap between NE, NNSA, Science (Fusion, High-Energy Physics, Isotopes), and naval reactors. The subcommittee therefore recommends joint development efforts - to include joint facilities - that have shared funding structure.

5) **NE should focus on strategies (including project management tools) to shorten the timescales for nuclear projects and a new science-based paradigm for material qualification and licensing process.**

The approximate timescale for major nuclear development facilities are as follows:

- A new test/research reactor takes 8-12 years to build and make operational.
- A new large-scale hot cell facility takes 6-10 years to build and make operational
- Even a shielded glow-box facility takes 4-6 years to build and make operational
- Developing a new fuel or a new alloy for use in reactors requires 20+ years to qualify, if there is limited previous experience with the materials (especially if a licensing phase is never completed)

The effort to shorten these timeframes presents an opportunity for joint efforts across DOE. Joint materials research could increase funding and perhaps help shorten development timelines.

Supply-Chain for Advanced Reactors

Component Supply Chain

The GAIN Advanced Reactor Supply Chain Assessment Report (INL/RPT-23-70928, April 2023) evaluated the supply chains for the ramp up in production of the following types of components for advanced reactors: graphite, sensors, vessel, heat exchangers, and pumps. The areas of risk identified are availability of knowledgeable and experienced workforce, uncertainty of orders and long lead times, production capacity expansion, and access to raw materials. The report calls for supply chain investments in the next 5 to 10 years, to aid the market in surpassing these supply chain risks that will inevitably be faced if advanced reactors are to be successfully deployed. The report also puts these risk factors in the context of international competition for meeting supply chain needs; international competition is further impetus for investment in development of US supply chains, and in supporting strategic international collaborations that work closely with reactor vendors for adapting capacity and products to meet the demands of a diverse range of advanced reactor technology.

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[1] https://www.nationalacademies.org/our-work/laying-the-foundation-for-new-and-advanced-nuclear-reactors-in-the-united-states

[2] https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Advanced-Nuclear-vPUB.pdf

Fuel supply chain.

6) **NE should prioritize implementation of the infrastructure necessary for commercialization of High Assay Low Enrichment Uranium HALEU advanced reactors.**

NE is working on a HALEU strategy to support advanced reactors demonstration and deployment. The hand-off to commercial enrichment companies is important. Understanding the production scales as a function of time must be seriously considered based on realistic data. There is a "chicken and egg" problem to be addressed whereby production cannot be scaled up before a large number of orders is received but orders will not be submitted until large-scale production can be demonstrated. The NAE studies on fuel cycle and Advanced Reactors identified this need as did prior NE Budget submissions. So there needs to be a longer-term focus, consistent with an overall recommendation to focus on the commercialization of nuclear technologies, on solving this problem, and stimulating production in the absence of specific orders with a recognition that there will be demand for the product once larger scale production is a reality.

The Subcommittee's recommendation is based upon the need to process as much HALEU as possible in the near term. Perhaps reprocessing highly enriched uranium from sources such as spent fuel from naval reactors could be a way to scale up production in the relatively short-term to "kick start" the supply chain. The reprocessed HEU with different levels of downblending can support multiple advanced reactor demonstrations and early deployment while allowing the industrial enrichment efforts to respond to the demand as the demand grows. Then, prioritizing the infrastructure to do the adequate level of reprocessing HEU fuel could be achievable more consistent with the public-private partnership model for HALEU supply without the government getting ahead of the industry in enrichment.

Another idea could be to leverage other DoD work through projects such as the BWXT Project Pele micro-reactor for both enrichment needs and fuel fabrication.

7) **Assuming nuclear energy production transitions to HALEU fuel (nationally and globally), reprocessing and recycling may need consideration. The issue of reprocessing HALEU fuel should follow along with addressing the large-scale supply issue addressing uranium utilization and supply reliability for the long-term. Light isotope enrichment should also be given consideration.**

Even for R&D scale of reprocessing of advanced reactor fuels, current facilities need major modifications. A demonstration scale recycling facility does not exist. Starting today and completing with demonstration, incorporating recycling into advanced reactor deployment would take 15-20 years. If the US wishes to keep the option of contributing to what may become a global demand for reprocessing of a broad range of advanced reactor fuels, the infrastructure and technology development foundations must be established today. Infrastructure and workforce investment in both conventional and pyro-processing methods should be considered. Recovery of enriched light isotope should also be considered, for example recovery of Li-7 or Cl-7 by used fuel reprocessing may at some point in the future prove to be commercially competitive with production of a new inventory of enriched light isotopes; synergy may exist with fusion energy as well. These areas may prove to have important overlap with the rapidly growing need for medical isotope production.

Short-term and long-term solutions for management of spent fuel and waste streams from reprocessing and decommissioning must be given consideration.

The diverse advanced reactor fuel forms, and potential waste streams from reprocessing operations and from decommissioning operations require a compatible set of waste acceptance criteria and options for packaging, transportation, interim storage and ultimate disposal.

Physical and Intellectual Infrastructure

8) **Establish tight coordination between the university infrastructure and national laboratory physical infrastructure programs with adequate access models (user facility models) to an integrated set of capabilities accessible by and also contribute to by industry. It appears this is successfully being done by Nuclear Science User Facility, which can be expanded by growing capabilities at universities with additional investments.**

Investment in user facilities is instrumental in sharing unique resources and knowledge and also in creating mentorship relationships and fostering work for development for nuclear scientists and engineers, and to some extent, for nuclear technicians. The university programs and NE infrastructure investments most directly support these facilities and should continue to do so guided by these objectives. Opportunities may exist for user facilities hosted by industrial entities; consideration should be given to funding and other incentive models that may facilitate engagement of industry partners.

9) **Develop a methodology to assess how well the different pieces of the existing infrastructure are being used to support the national priorities across the different time-scales and evaluate if there are some savings there by repurposing or shutting down facilities with little or no interest to free up funding for other priorities. Determination of the most important capabilities relevant short-term and long-term priorities that MUST be preserved to support the nuclear energy strategy with quantitative analysis of benefits would be very informative.**

NE budget request for FY'2024 provides a good understanding of the cost of nuclear R&D. Maintaining the existing infrastructure is expensive and consumes a considerable fraction of NE's budget. This leaves little room for funding innovative research and responding to emerging industry needs for shared infrastructure. Maintaining what we have and supporting the immediate needs of the industry is also vitally important. The Subcommittee's impression from the presentations we have received is that NE's efforts, while certainly coordinated and managed, are not necessarily focused based on an established set of national priorities. That is difficult to accomplish given that national priorities change with the political winds, but having a set of overarching priorities would help make sure that investment in general and in infrastructure specifically is directed toward efforts that are in line with those priorities. The Subcommittee therefore believes that a review should be done of existing infrastructure. This should include an assessment of what should be returned to industry for lead (like LWR Sustainability). Also - NRIC has expended significant resources on facilities to support demonstration and test - this should be reviewed to see what else needs to be done (or what should be eliminated), and what can be done in synergy with other efforts. **Achievement of milestones should be tied to increased funding levels, to encourage success and ensure sustainability.**

Time-Scale for New Infrastructure supporting Advanced Reactors

10) **NE should obtain clearer input from industry perhaps through a workshop between NE and the Working Groups, or some other form of face-to-face interaction that results in meaningful prioritization of the Working Group feedback, especially as it pertains any needs for new or modified infrastructure. NE should facilitate a mechanism for receiving that clarified feedback given the Subcommittee's impression that additional interaction with and information from the industry would be beneficial in accomplishing other of our recommendations focused on commercialization of nuclear technologies in the near and long term.**

The review of the input provided by the GAIN industry Working Groups established under NEI by the GAIN program were not very useful. Some are just a wish-list without any specificity especially by the molten salt group (what kind of salt, what scale, what is the timeline, etc…). The Fast Reactor Working Group would like to have a test reactor but given that the versatile test reactor project is halted by Congress, it would be helpful to know the impact on their plans. We know at least one company is proceeding with demonstration despite the lack of testing for fuels and materials for fast spectrum reactors. The High temperature reactor community appears to just want the completion of ongoing tests in the DOE complex even through some of these tests do not cover their desired design options and it is not clear the infrastructure exists to perform the missing experiments.

R&D Infrastructure

11) **NE should establish R&D priorities specifically with respect to infrastructure with an emphasis on R&D that accelerates the bridge to commercial deployment. There should also be a definitive tie between the R&D programs to the ARDP and other demo programs.**

The area where NE has more direct control over investment strategies and priorities is on the R&D infrastructure.

Potential Follow-on Topics for the Subcommittee

- The Subcommittee could help to continue to develop priorities for funding. We would need additional (perhaps ad hoc) members in the subcommittee with expertise outside the NEAC members in some of these topics.

- Given that developing a comprehensive R&D infrastructure is expensive and of long-duration, further insight into NE's strategy to leverage international R&D infrastructure especially with like-minded nations and nations with which we want to do business in the area of advanced reactors would be helpful. If there is a strategic approach to this topic through various international collaboration agreements, a presentation would be beneficial to the subcommittee.

- The infrastructure issues for large-scale commercialization of advanced reactors (supply chain infrastructure) are very complex. Because of the large lag-time and high capital investment needs, the standard loan guarantee and tax credit models are not very adoptable to private investment for nuclear energy supply chain. DOE-NE has limited influence on structuring a new model more appropriate for nuclear energy paradigm. If this is an area of interest for our subcommittee to focus on, we should augment the subcommittee with appropriate expertise with experience on public-private financing high-risk projects. Can the existing mechanisms work or is a new paradigm necessary? Who owns them? What can NE do to make them actionable?

- Separating the intellectual infrastructure (workforce) and physical infrastructure is difficult and these needs need to be addressed together or in concert with each other. Workforce development efforts should be broad and not just university centric. If/when the workforce subcommittee identifies the physical infrastructure needs to support the desired workforce outcomes, the Infrastructure Subcommittee then could identify the existing infrastructure that can support those needs with some upgrades/modification or identify major gaps that require major new investments.