NRIC National Reactor Innovation Center

National Reactor Innovation Center Strategy for Advancing Nuclear Integrated Energy Systems

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Table of Contents

Figures

1. OVERVIEW

1.1. What is IES?

Integrated energy systems (IES) combine low-carbon energy sources to meet demand for clean energy in multiple forms across multiple sectors of the economy. IES create opportunities to cost-effectively dispatch generation resources to balance electricity supply and demand. In addition to producing electricity, IES increase the value of non-emitting energy sources by integrating generation technologies with industrial processes to efficiently produce commodities that benefit the manufacturing, industrial processing, and transportation industries. Nuclear energy technology is key to enabling these benefits. Advanced nuclear reactors capable of producing high-quality heat and electricity will play a foundational role in IES of the future.

1.2. Why is *Nuclear* IES important?

As municipalities, states, electric and gas utilities, and private companies across the United States and the world set aggressive goals for reducing carbon emissions, industry leaders have recognized that renewables backed by natural-gas peaking plants and battery energy storage are insufficient to meet those goals. A broader portfolio of technologies is needed to achieve a low-carbon energy economy that is both affordable and reliable [1]. Advanced nuclear technology promises flexible operations for integrating with variable grid resources [2]. It also enables clean, low-cost production of hydrogen as an energy carrier and the provision of high-quality heat for industrial processes. Finally, radiation produced in the fission process could be leveraged to catalyze key reactions in chemical processes.

1.3. What is NRIC's role with Nuclear IES?

The National Reactor Innovation Center (NRIC) will conduct IES development and demonstration in partnership with private industry and the DOE Office of Nuclear Energy Crosscutting Technology Develop Integrated Energy Systems (CTD IES) program. NRIC will empower private-sector innovators to advance nuclear IES technologies from pre-conceptual design to pilot-scale demonstration. NRIC will provide partners access to unique demonstration testbeds, modeling and simulation capabilities, and scientific expertise at multiple national laboratories. These efforts will be carried out in partnership with CTD IES and the IES initiative at Idaho National Laboratory (INL), which is developing and demonstrating multi-generation energy systems that—by incorporating nuclear energy—provide grid reliability, resilience, and affordability across energy-use sectors [3,4].

This document describes NRIC's strategy for IES demonstration that will leverage its unique resources, capabilities, and partnerships. The strategy described in this document is based on a proven framework for defining private-sector corporate strategies, adapted for a federally funded research, development, and demonstration program [5].

1.4. How will NRIC make an impact?

Successful execution of this strategy will allow private firms to demonstrably increase the technology readiness level (TRL) of advanced nuclear IES technology, with the goal of achieving TRL 7 by 2027.[1] NRIC will also provide critical new knowledge to the broad range of stakeholders who are looking to IES technology to enable them to meet carbon-reduction goals. These outcomes will benefit both private technology developers and end users of the technology, including both energy producers and industrial energy consumers. NRIC's work will also guide public and private research agendas, policy decisions, and investments.

2. OBJECTIVE

NRIC will partner with CTD IES and private technology developers to develop, test, and demonstrate IES technologies for both end-use applications (e.g., energy storage devices) and interface hardware (e.g., heat exchangers, heat transfer systems) to accomplish the following two objectives:

1. Understand the performance and cost of nuclear IES, in order to test industry's hypotheses for the markets, conditions, and applications in which nuclear IES is competitive with conventional technologies
2. Identify and overcome technological challenges and risks to commercialization of nuclear IES in high-potential markets and applications.

The first objective addresses the question, "How should IES be commercialized to be successful?" The second objective addresses the question, "How can IES be successfully commercialized?" Testing and pilot-scale demonstration will specifically allow innovators working with NRIC to do the following actions to meet these objectives:

- Characterize the performance, efficiency, durability, and operating cost of IES technology coupled with advanced reactors
- Identify unforeseen issues, system interactions, costs, and performance limitations that arise when scaling technology; also identify unforeseen efficiencies and opportunities
- Validate system interface requirements, assumptions, and models used to quantify the performance, efficiency, cost, and value of IES deployment
- Demonstrate industry partners' control strategies and conduct experiments and testing to allow them to improve and validate controls.

[1] TRL7 is defined as a system prototype demonstration in an operational environment (i.e., integrated pilot). The system is at or near full scale (pilot or engineering scale) of the operational system, with most functions available for demonstration and testing. The system or process is integrated with ancillary systems in a near-production quality prototype.

3. APPROACH

3.1. Applications of Focus

NRIC will focus its nuclear IES development, testing, and demonstration on resolving key questions and uncertainties that would enable one or more of the following five applications:

1. Microreactor and thermal-energy transport system delivering electricity and process heat for high-temperature steam electrolysis to produce hydrogen that meets requirements of the U.S. electric utility, transportation, petroleum/petrochemical, and/or steel manufacturing industries (see Figure 1)

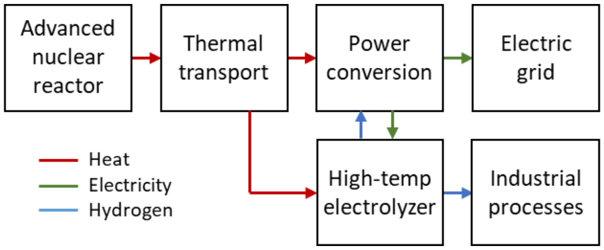

Figure 1. Hydrogen production using high-temperature electrolysis.

2. Microreactor and thermal-energy transport system delivering process heat to a thermochemical system that produces hydrogen, synthetic fuels, or other chemical products that meet the requirements of U.S. electric utility, transportation, petroleum/petrochemical, and/or steel manufacturing industries (see Figure 2)

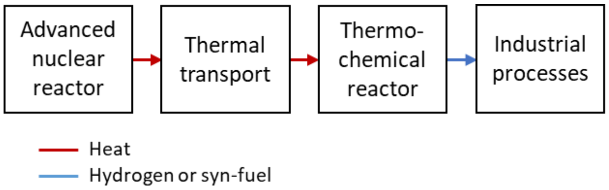

Figure 2. Thermochemical production of hydrogen and other chemical products.

3. Microreactor and thermal-energy transport system delivering process heat for the U.S. chemical and petroleum/petrochemical industries (see Figure 3)

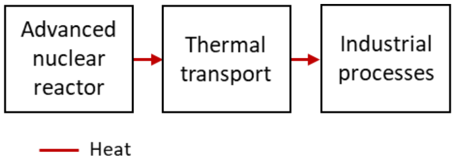

Figure 3. Heat as a direct input to industrial processes.

4. Microreactor producing radiation and heat for radiation-thermal cracking to reduce the energy required for chemical processes in the U.S. petroleum/petrochemical industry (see Figure 4)

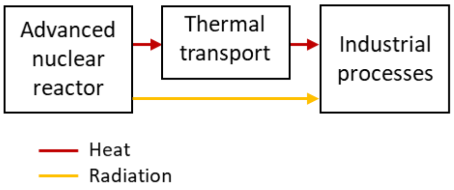

Figure 4. Heat and radiation as direct inputs to industrial processes.

5. Microreactor coupled with distributed electrical energy resources (e.g., local renewables, stationary battery-energy storage, etc.) on a microgrid to serve residential, commercial, industrial, and/or electric transportation loads (see Figure 5).

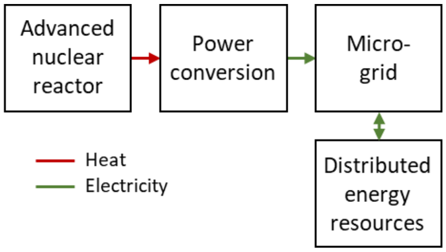

Figure 5. Electricity production integrated with distributed energy resources

Note: In some cases, combinations of these architectures could be simultaneously demonstrated.

3.2. Capabilities

To accomplish its objectives, NRIC will develop its own foundational capabilities and expertise; partner with researchers at INL and other national laboratories to gain access to additional capabilities; and partner with private companies to plan and execute demonstrations.

NRIC will leverage existing capabilities and develop additional capabilities, as needed, to design and execute nuclear IES tests and demonstrations with actual advanced reactors, such as the Microreactor Applications Research Validation and Evaluation Project (MARVEL), demonstration microreactor(s), and/or the Versatile Test Reactor NRIC will also coordinate with CTD IES to translate market needs into technical requirements and use cases for IES technology, working with experts in the DOE laboratory system, industry, and academia, leveraging the Advanced Reactor IES Expert Group established by CTD IES in FY20. In collaboration with other subject matter experts, a market evaluation team will down-select target applications and establish public-private partnerships to develop and demonstrate IES technology for those applications.

NRIC will partner with national laboratories to access capabilities of other programs, as follows:

- Economic, physics, and system-optimization modeling and simulation (INL, ANL, and ORNL, via CTD IES program)
- Access to an advanced reactor emulator and other IES research laboratory facilities (INL's Microreactor Agile Nonnuclear Experiment Testbed [MAGNET] and Dynamic Energy Transport and Integration Laboratory [DETAIL])
- System/process technology and controls expertise (INL, PNNL, ANL)

NRIC will partner with energy producers (e.g., electric utilities), IES subsystem/component suppliers, advanced reactor developers, and energy users (e.g., petrochemical companies) to access system/process technology and controls expertise, obtain system/process hardware, and conduct testing and demonstration. Perhaps most importantly, NRIC will act as an interface between firms and facilitate discussions between partners to empower them to achieve optimal design and operation at the overall system level.

3.3. Differentiation

NRIC will provide partners access to unique demonstration testbeds employing emulated and actual advanced reactors at different scales. These testbeds provide partners with unique opportunities to implement and test entire IES systems, downstream thermochemical processes, and individual subsystems, such as electrolyzers and thermal energy storage systems. Incorporation of emulated and actual microreactors allows developers to explore complex system interactions not present in individual subsystem testing, experiment with different working fluids, and validate modeling and simulation results. They also provide the means to develop and demonstrate control strategies for managing intricate trade-offs of coupled systems, such as balancing the distribution of microreactor heat transfer between power conversion and non-electric applications (e.g., hydrogen production) in response to changing grid conditions.

3.4. Staging over Time

1. FY21: Advanced reactor IES demonstration platform pre-conceptual/conceptual design

   NRIC will work with INL subject-matter experts to conduct market and technology analyses and select one or two nuclear-based IES applications of focus. NRIC will then use the concept-of-operations framework to design an IES testbed that will enable demonstration of the application(s) of focus.

2. FY21-22: Partnership development and teaming

   NRIC and INL, in collaboration with CTD IES, will identify and engage with target industry partners to establish a team (or teams) of energy producers, IES subsystem suppliers, advanced reactor developers, and energy users who will devote resources to IES demonstration.

3. FY21-25: Testbed development

   NRIC and INL, in collaboration with CTD IES, will develop nuclear IES testing and demonstration capabilities, including testbeds in the Energy Systems Laboratory and at INL desert site facilities.

4. FY22-25: Proof of concept and engineering feasibility demonstrations to achieve TRL 5-6

   NRIC will partner with INL, other national laboratories, and industry partners to conduct subsystem and process testing with emulated (e.g., MAGNET) and actual (e.g., MARVEL) advanced reactors. This testing will partially integrate IES subsystems with advanced reactors. Digital emulation techniques will be used to represent boundary conditions.

5. FY26-27: Pilot-scale demonstration to achieve TRL 7

   NRIC will partner with INL, other national laboratories, and industry partners to test and demonstrate nuclear IES systems at pilot scale with most functions integrated.

3.5. Funding

This strategy assumes that DOE’s Office of Reactor Fleet and Advanced Reactor Deployment (NE-5) will fund NRIC testbed capability development, planning and analysis, and partnership development. Funding for development, testing, and demonstration activities in partnership with industry will be secured through various channels, including DOE funding opportunity announcements, strategic partnership programs, and joint industry projects (i.e., multi-party CRADAs).

4. OUTCOME

Accomplishing the objectives of NRIC's nuclear IES strategy will accelerate development and commercialization of new technology that will enable affordable, clean energy and energy products for multiple sectors of the economy. It will also maximize the value of advanced nuclear technology and demonstrate its important role in achieving low-carbon energy goals. Successful execution of this strategy will also strengthen NRIC by establishing a suite of interwoven, reinforcing capabilities and activities that allow innovators to conduct cutting-edge research, development, and demonstration impossible to achieve elsewhere.

5. REFERENCES

1. Energy Industry Executive Panel, EPRI Low-Carbon Resources Initiative Virtual Roundtable, September 1, 2020.

2. "Flexible Nuclear Energy for Clean Energy Systems," NREL/TP-6A50-77088, September 2020, https://www.nice-future.org/flexible-nuclear-energy-clean-energy-systems.

3. "INL Integrated Energy Systems Strategic Plan 2020," INL/LTD-20-58863.

4. Bragg-Sitton, S., et al., "Integrated Energy Systems: 2020 Roadmap," INL/EXT-20-57708 Rev. 1.

5. Hambrick, D. Fredrickson, J. "Are you sure you have a strategy?" Academy of Management Perspectives vol. 15, no. 4. doi.org/10.5465/ame.2001.5897655. 2001.

6. APPENDIX

Appendix A, INL IES Initiative

Appendix A
INL IES Initiative

The objectives of INL's IES initiative, paraphrased from the 2020 INL IES Strategic Plan [3], are as follows:

1. Optimize IES design and operation, based on market-driven analysis and controls development
2. Enhance ROI for thermal generators (i.e., nuclear reactors) by demonstrating the technical feasibility of large-scale alternative energy products and pathways
3. Develop and demonstrate economic (thermal) energy storage and use technologies, and processes that better integrate with nuclear-generated heat and, when appropriate, radiation
4. Develop and demonstrate approaches to utilizing nuclear energy products to create electric and non-electric value streams for new applications and use.

To accomplish these objectives, research, development, and demonstration is necessary in the following three areas:

- **Thermal systems –** demonstrate the generation, storage, delivery, and use of high-quality thermal energy products, primarily from nuclear sources, to support industrial processes and grid infrastructure, culminating in at-scale demonstrations
- **Electron systems –** coordinate the generation, distribution and use of traditional and intermittent electricity sources to enhance the stability, security, and economics of power systems
- **Energy to molecules and materials –** design and develop novel chemical processes driven by low-emissions energy resources (thermal, electrical, and possibly ionizing energy [i.e., radiation]) to upgrade and transform feedstock into higher-value molecules, chemicals, or materials.

The end product of INL's IES initiative is a fully integrated, at-scale demonstration of multiple IES configurations to reduce the risk for commercial deployment.