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Summary of INL Integrated Energy Systems Research for the Global National Laboratories Consortium on IES

June 2023

Shannon M Bragg-Sitton

Changing the World's Energy Future

Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Summary of Idaho National Laboratory Integrated Energy Systems Research for the 2023 Annual Report of the Global National Laboratories Consortium on IES

May 2023

The DOE Office of Nuclear Energy (DOE-NE) program on Integrated Energy Systems (IES) is led by researchers at Idaho National Laboratory (INL), and work is conducted in partnership with an array of other DOE laboratories, industry, and academia. IES research and development activities are additionally complimented by the DOE-NE Light Water Reactor Sustainability (LWRS) program, where work under the Flexible Plant Operations & Generation pathway supports analysis of opportunities for non-electric applications of current fleet nuclear plants and collaborates with multiple plants on near-term hydrogen production demonstration opportunities. The DOE-NE programs additionally partner with the Hydrogen and Fuel Cell Technologies Office under the DOE Office of Energy Efficiency and Renewable Energy to jointly fund the development of analysis tools, technologies, and nuclear-integrated hydrogen demonstration projects.

The primary focus of DOE-NE IES research is to assess the technical and economic potential of nuclear-driven IES to enhance the flexibility and utilization of nuclear reactors working alongside renewable generators to meet an array of energy demands—thereby maximizing the utilization of clean energy resources across all energy sectors. Various energy applications and product streams beyond electricity are being evaluated, ranging from generation of potable water to production of hydrogen, fertilizers, synthetic fuels, and various chemicals.

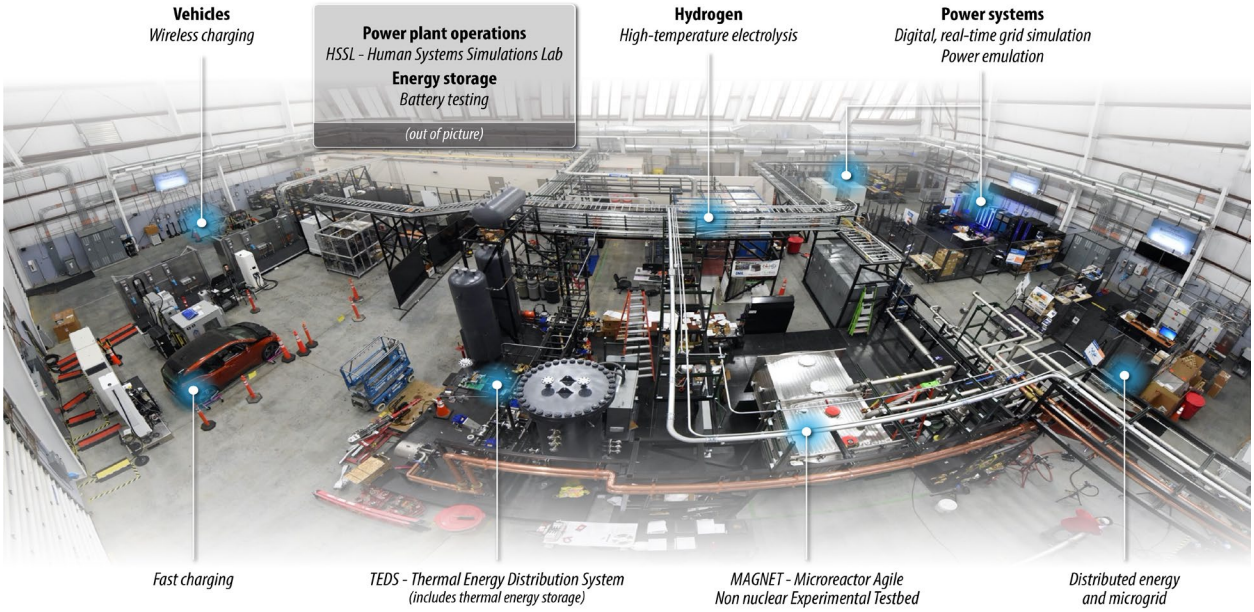
Advances in IES Modeling, Simulation, and Optimization

INL, working in partnership with other U.S. national laboratories and universities, has developed the Framework for Optimization of ResourCes and Economics (FORCE) for energy system design and optimization. FORCE supports analysis of the technical and economic feasibility of candidate energy systems operating within specific energy markets and supporting multiple product markets (for more information and to access training modules see https://ies.inl.gov/SitePages/FORCE.aspx). FORCE and its various plug-ins support evaluation of the integrated operation of multiple reactor types, renewable technologies, and energy users across the electricity, industry, and transportation sectors. Input data are required for the intended energy market and how that market might fluctuate over time; time-dependent data for renewable energy sources based on historical datasets; financing details such as capital costs, interest rates, and rate of return. The models employed by FORCE represent detailed dynamic operations of the various interconnected subsystems, determining optimal subsystem capacities and realtime dipatch. Dynamic models currently include multiple rector technologies, thermal and electrical energy storage, desalination, hydrogen production, balance of plant options, and other necessary components and subsystems. The FORCE tool suite is available as open source via github.

INL has led numerous feasibility studies, many in partnership with other national laboratories and private industry, some of which are now leading to operational systems. Analysis reports associated with enhanced utilization of currently operating light water nuclear plants are primarily issued via the LWRS Flexible Plant Operation & Generation Pathway (https://lwrs.inl.gov/SitePages/GroupedReports-sorted.aspx?ReportCategory=Flexible%20Plant%20Operation%20and%20Generation). Reports covering simulation tool development and enhancements and application of FORCE to advanced reactors are generally issued via the IES program (https://ies.inl.gov/SitePages/Reports.aspx).

Experimental Demonstration

INL has established a nonnuclear facility to test novel systems integration, providing opportunity to conduct lab-scale testing and demonstration of individual or coupled technologies in order to demonstrate performance characteristics, integration approaches, and system control options—using electric heating to represent the heat that would be provided by a nuclear reactor. The test facility includes a microreactor testbed, thermal energy distribution, high-temperature electrolysis components and systems, power systems emulation, and microgrid infrastructure.



Detailed studies on the utilization of existing fleet nuclear plants for hydrogen production via low temperature or high temperature electrolysis (LTE or HTE) are now resulting in cost-shared (public/private funding) demonstrations at three U.S. nuclear plants. In March 2023 the Constellation Nine Mile Point Nuclear Plant in New York began onsite production of hydrogen using nuclear power coupled to LTE deployed onsite. This demonstration will be followed by hydrogen production at the Energy Harbor Davis-Besse Nuclear Power Station, also using LTE, and the Xcel Energy Prairie Island Nuclear Generating Plant using higher-efficiency HTE.

These early LWR-based demonstrations provide a strong foundation for thermal and electrical integration of non-grid energy users (e.g., hydrogen production, among others) with greenfield projects. Advanced reactors are designed to operate at higher temperatures, run more efficiently, and provide greater flexibility than LWRs, making them ideally suited to many industrial heat users. These systems are available at a range of capacities, allowing them too work in concert with renewables power microgrids in isolated communities, supply heat and electricity to remote mining operations, provided dedicated energy for large hydrogen markets and so much more.

INL is the U.S. DOE lead laboratory for nuclear energy and also leads development and demonstration of high temperature electrolysis for hydrogen production. INL partners with multiple steam electrolysis companies to demonstrate performance of individual solid oxide electrolysis stacks and complete systems as private industry seeks to advance their technologies to achieve to commercial-scale hydrogen production. From 2022 to 2023, in collaboration with Bloom Energy, INL has operated a 100-kWe Bloom

HTE system for over 4000 hours under both steady state and transient conditions. INL is now preparing to receive a 250-kWe HTE system from FuelCell Energy for testing and is finalizing construction of an "open architecture" system that will support advancement of HTE systems from other vendors.

Engaging an International Audience

INL and NREL jointly support the Nuclear Innovation: Clean Energy Future (NICE Future) initiative under the Clean Energy Ministerial. Two key publications were issued by NICE Future in 2022. The *Nuclear Hydrogen Digest: The Role of Nuclear Energy in the Hydrogen Economy* showcases examples of leading nuclear energy based hydrogen initiatives around the world which can be used to power hard-to-electrify sectors such as transport and heavy industry. Additionally, the Research the Impacts on Social Equity and Economic Empowerment (RISE3) initiative was launched under NICE Future. The first action for RISE3 was to develop the RISE3D case study series, which includes submissions from participating countries and partner organizations that demonstrate how advanced and innovative nuclear energy technologies, such as small modular reactors, will support the clean energy transition in a variety of community contexts.