HYDROGEN

Our energy future
begins at INL

Idaho National Laboratory

THE IDAHO NATIONAL LABORATORY is home to state-of-the-art hydrogen testing capabilities led by the field's most prominent researchers. These capabilities range from fundamental materials research to industrial-scale nuclear reactor integration demonstrations.

UTILITIES AND MANUFACTURING COMPANIES CAN PARTNER WITH INL TO EXPLORE THESE NEW ADVANCED ENERGY TECHNOLOGIES. INTEGRATING HYDROGEN PRODUCTION AND USE INTO THEIR PROCESSES CAN IMPROVE EFFICIENCIES, INCREASE PROFITS AND HELP SECURE THE NATION'S ENERGY FUTURE.

Bloom Energy's electrolysis system being tested at INL's Energy Systems Laboratory.

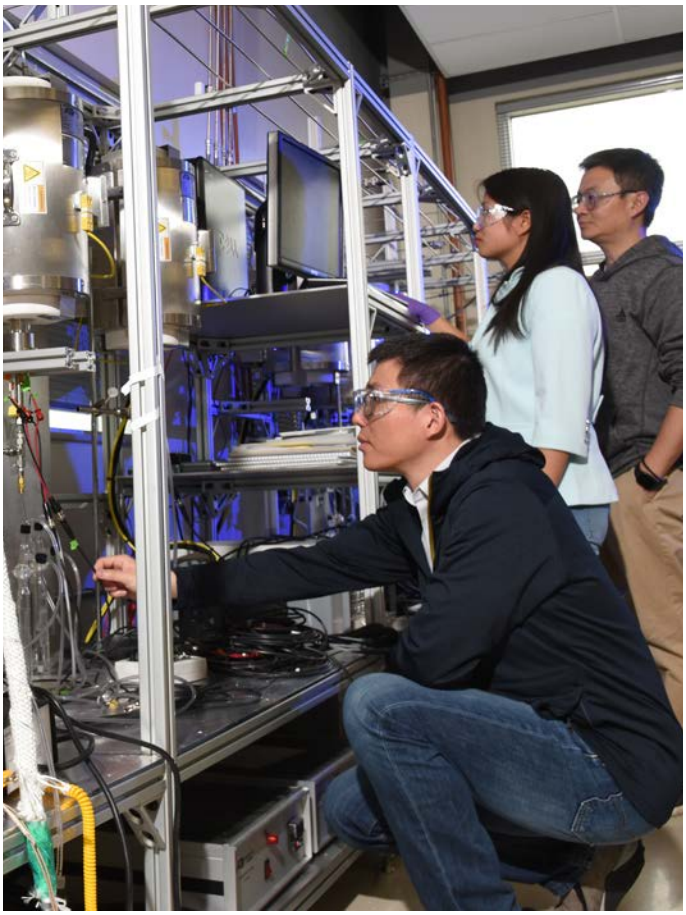
Proton-conducting solid oxide electrolysis cells (SOEC) materials development

Material experts are leading the development of protonic ceramic electrochemical cells (PCECs) to produce hydrogen. Some key advantages of this technology include:

- Applicable to both splitting steam and selectively removing hydrogen from methane, ethane and higher alkanes
- Operating temperature under 600 C
- High ion conductivity
- Low activation energy
- Pure hydrogen generation
- Simple system with reduced components
- Direct hydrogenation with a variety of feedstock including carbon dioxide and nitrogen

These benefits may reduce the cost of electrolytic hydrogen production.

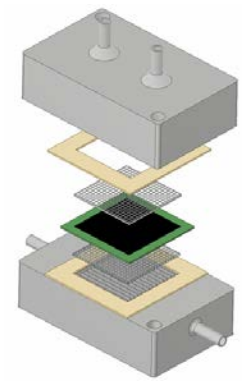
For more information about this work and potential partnership opportunities, please contact Dong Ding, Dong.Ding@inl.gov.



SOEC materials development at INL's electrochemical processing laboratory.

Electrocatalysis with proton-conducting SOEC

INL researchers are developing novel electrochemical applications of PCEC for producing polymers and ammonia.



View of a SOEC's components.

The process for producing valuable polymers starts by extracting hydrogen from methane, ethane and propane. Pure hydrogen is a byproduct of this step. Ammonia can be produced by combining protons (hydrogen ions) with nitrogen in the PCEC hydrogen electrode. INL has patented novel catalysts for both of these potentially revolutionary chemical synthesis options.

For more information about this work and potential partnership opportunities, please contact Dong Ding, Dong.Ding@inl.gov.

Accelerated stress testing: Cells and small stacks

The U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office sponsors the national lab consortium for Hydrogen from Next-generation Electrolysis of Water (H2NEW).

H2NEW is helping industry understand and extend the operating life of high-temperature electrolysis cells through accelerated stress testing using multiple stations for button-cell and large, planar-cell test stands. This testing improves the fundamental understanding of degradation processes which has enabled the development of novel operational approaches that improve performance and reduce degradation.

In 2025, INL added a high-pressure (750 psi rating, or ~50 bar) stand to its capability for testing single cells or small stacks.

For more information about this work and potential partnership opportunities, please contact Micah Casteel, Micah.Casteel@inl.gov.

Stack and module testing: 1– 50 kWe

INL's Energy Systems Laboratory features several full-size commercial stack testing units to validate performance and durability.

These systems can operate unattended for thousands of hours using advanced hydrogen recycle systems and communication functions to alert the test leads if unusual operating conditions are detected.

Independent stack testing helps companies prove technology readiness for installation in larger pre-commercial modules.

The units operate by supplying the necessary reactants to feed a high-temperature steam electrolysis stack including de-ionized steam, hydrogen, nitrogen, compressed air and safe gases within a thermally controlled environment. The system uses an uninterrupted power supply system to maintain operation even during grid anomaly events.

INL's real-time grid simulation and associated grid power conditioners are located with these systems, which enables test stands to investigate real-world duty cycle ramping impacts on stack performance.

For more information about this work and potential partnership opportunities, please contact Micah Casteel, Micah.Casteel@inl.gov.

HTE system testing and demonstration: 100 – 500 kWe

INL supports commercial developers looking to design, operate and prove the performance of fully integrated High Temperature Electrolysis (HTE) modules.

The first unit to be tested was developed under a Cooperative Research and Development Agreement with Bloom Energy, with power input of over 100 kWe DC.

For more information about this work and potential partnership opportunities, please contact Micah Casteel, Micah.Casteel@inl.gov.

HTE 25 kW stack test station at INL's Energy Systems Laboratory.

FuelCell Energy's 250 kW HTE system being delivered at INL.

More recently, FuelCell Energy and INL teamed up on a DOE cost-shared project to test a 250 kWe DC modular HTE unit. In January 2025, FuelCell Energy's new 250 kWe solid oxide electrolyzer arrived at INL where it will be tested and validated.

Following commissioning and system verification, this unit will be tied to a gas conditioning and compression system to supply hydrogen to research systems such as methanol production and cofired natural gas-hydrogen turbines.

For more information about this work and potential partnership opportunities, please contact Micah Casteel, Micah.Casteel@inl.gov.

INL can support other HTE modules for testing to raise the technology readiness for commercial use while enhancing safety and reducing technical risks. These may include units for:

- Reverse water-gas shift reactor for synthesis gas generation (H_2 + CO mixtures)
- Ammonia synthesis
- Synthetic natural gas from CO and H_2
- Synthetic fuels synthesis
- Hydrogen fuel cell testing
- Hydrogen blending with industrial gases

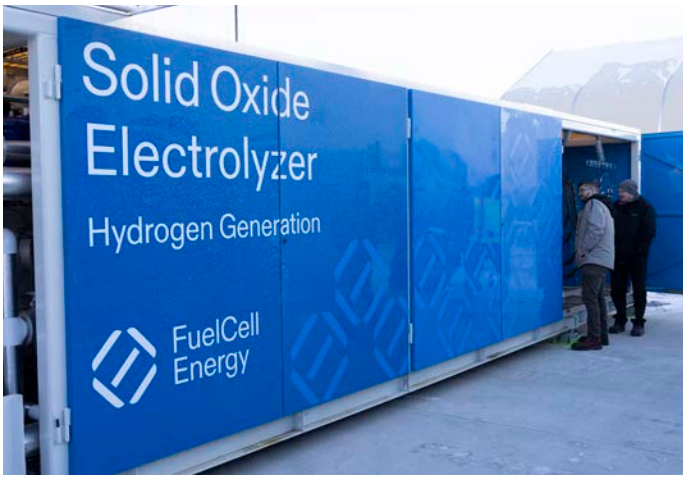
For more information about this work and potential partnership opportunities, please contact John Moorehead, John.Moorehead@inl.gov.

Integrated systems testing

Integrated energy systems are essential to developing nuclear-supported hydrogen production. The IES program has established a diverse, non-nuclear facility to support model validation and initial technology demonstration.

With integrated energy systems, existing nuclear plants or future advanced reactors can switch between providing electricity to the grid and producing hydrogen, depending on the grid demand and energy cost. This will result in higher profits for nuclear reactor operators.

For more information about this work and potential partnership opportunities, please contact Richard Boardman, Richard.Boardman@inl.gov.



FuelCell Energy's 250 kW HTE system being tested at INL's Energy Systems Laboratory.

Electrochemistry equipment to develop and test SOEC materials at INL's electrochemical processing laboratory.

Energy Systems Laboratory

Much of INL's leading hydrogen research occurs at the Energy Systems Laboratory. Here, researchers develop interfaces needed for a nuclear plant to dispatch thermal energy and electricity between a hydrogen plant and the grid.

To prepare a nuclear plant to operate under this paradigm, data links connect the Energy Systems Lab to INL's Human Systems Simulation Laboratory for process monitoring and control.

For more information about this work and potential partnership opportunities, please contact Micah Casteel, Micah.Casteel@inl.gov.

Human Systems Simulation Laboratory

The Human Systems Simulation Lab is a novel capability where researchers study human factors on a physical simulator of a nuclear power plant operator control room. The benefits this lab offers to hydrogen production include:

- Developing the thermal and electrical connections between the nuclear and hydrogen plants
- Supporting development of secure operating systems, operating concepts and data links between the plants
- Developing and testing human factors to ensure safe operations
- Demonstrating the ability to support the grid with specific reserve capacity
- Developing sensors and demonstrating system diagnostic and prognostic control

INL has entered a cooperative agreement with Westinghouse Electric Corporation and GSE Systems to develop simulators and prove operating concepts and control systems that will enable nuclear plants to dispatch energy to close-coupled hydrogen plants.

For more information about this work and potential partnership opportunities, please contact Tom Ulrich, Thomas.Ulrich@inl.gov.

Hydrogen production demonstrations at nuclear power plants

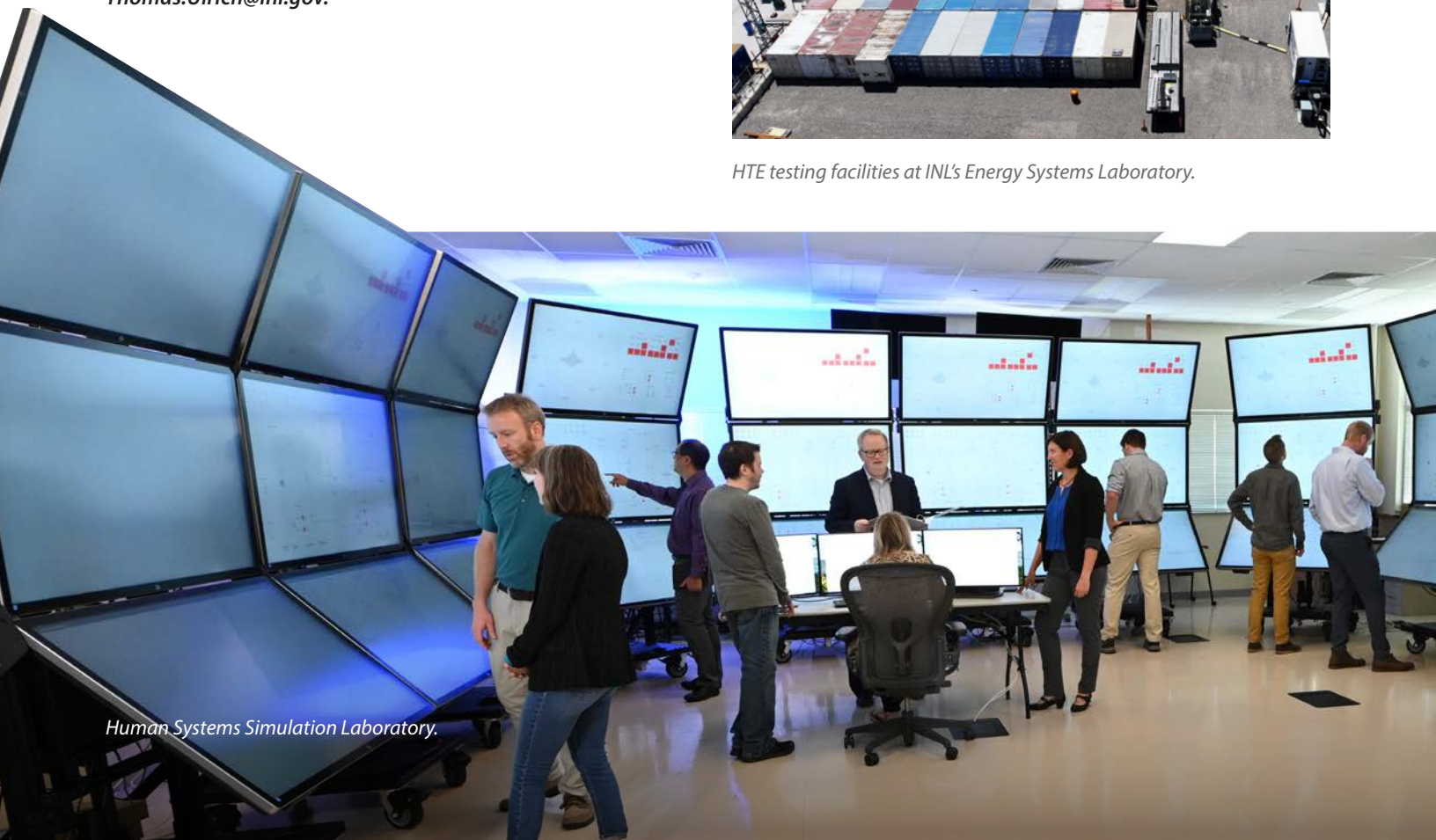
INL is supporting industry with DOE cost-shared electrolysis demonstration projects at existing nuclear power plants.

INL supports these projects with experimental test plan development and execution. The following projects are underway at operating nuclear plants:

- Constellation, Nine Mile Point Nuclear Station
- Xcel Energy, Prairie Island Nuclear Generating Plant

For more information about this work and potential partnership opportunities, please contact Tyler Westover, Tyler.Westover@inl.gov.

HTE testing facilities at INL's Energy Systems Laboratory.



Human Systems Simulation Laboratory.

High Temperature Test Facility

INL is expanding its hydrogen production capabilities with the construction of a new megawatt HTE test bed at the High Temperature Test Facility (HTTF). This facility will support industry adoption by providing large-scale testing and validation of hydrogen production technologies. The HTTF can supply up to 10 megawatts of input power, producing up to 6 metric tons of hydrogen per day.

It will also test and demonstrate hydrogen fuel cells, reversible SOEC, energy storage with hydrogen and integration with downstream processes. This initiative aims to scale up hydrogen production technologies to commercial levels, supporting the integration of nuclear power and other energy sources for efficient, flexible and reliable energy solutions on a commercial scale.

For more information about this work and potential partnership opportunities, please contact John Moorehead, John.Moorehead@inl.gov.

Modeling and simulation

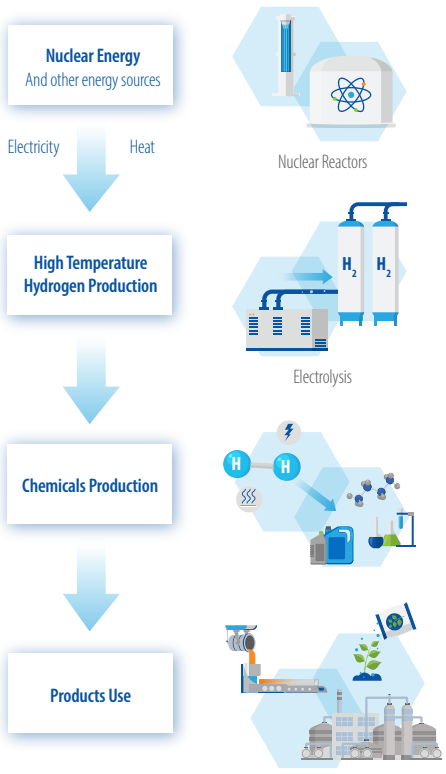
Modeling and simulation are key capabilities with far-reaching implications for hydrogen production. Specific INL modeling capabilities include:

- Fundamental HTE stack and module design using dynamic models
- Thermal hydraulic modeling
- Plant design, technical evaluations and economic assessments
- Holistic systems integration and optimization
- Digital twins (or virtual models) and real-time plant simulation
- Integration of hydrogen and nuclear plants with grid markets

For more information about this work and potential partnership opportunities, please contact Todd Knighton, Lane.Knighton@inl.gov.

Support facilities for the HTE capabilities (electric distribution systems, boilers, water desalination system, etc.) at the HTTF.

Installation of an HTE system at the HTTF.



Hydrogen production and use process.

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy

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