INL/EXT-21-64657

IDAHO NATIONAL LABORATORY

FY2021 LAB OVERVIEW

CHANGING THE WORLD'S ENERGY FUTURE

Idaho National Laboratory

Information about the Office of Nuclear Energy

The Office of Nuclear Energy (NE) mission is to advance nuclear energy science and technology to meet United States (U.S.) energy, environmental, and economic needs.

NE has identified five goals to address challenges in the nuclear energy sector, help realize the potential of advanced technology, and leverage the unique role of the government in spurring innovation:

1. Enable continued operation of existing U.S. nuclear reactors.
2. Enable deployment of advanced nuclear reactors.
3. Develop advanced nuclear fuel cycles.
4. Maintain U.S. leadership in nuclear energy technology.
5. Enable a high-performing organization

https://www.energy.gov/ne/about-us

Information about the Idaho Operations Office

Department of Energy Idaho Operations Office (DOE-ID) oversees major contracts, including Battelle Energy Alliance (BEA), to ensure that operations and research and are carried out safely, and in compliance with laws, regulations and contract provisions. DOE-ID also performs procurement services for the department, protects and conserves government property, and performs other inherently federal functions including compliance with the Freedom of Information Act and Privacy Act, congressional relations, and carrying out the department's responsibilities with the Shoshone-Bannock Tribes.

https://www.id.energy.gov/insideNEID/ManagersMessage.htm

Disclaimer

CONTENTS

LETTER FROM THE DIRECTOR

In December 2020, I became director at Idaho National Laboratory (INL). It is an honor to lead an organization working to improve the lives of the American people by changing the world's energy future and securing the nation's critical infrastructure.

The COVID-19 pandemic changed how we live and work. Through it all, INL remained focused, learned important lessons, adjusted, and delivered outstanding mission-focused results for the nation. I am grateful to our staff for their dedication and determination and am proud of our accomplishments to date. But now it is time to look forward.

Important projects and initiatives are underway at INL. Our workforce is talented, dedicated to its clean energy and national security missions, and determined to succeed. The laboratory is growing, and our culture continues to evolve. INL can change the world's energy future by being bold, innovative, and deliberate in our thoughts and actions, and by focusing on outcomes that matter. We will dream big, execute, collaborate, and be receptive to change.

INL's mission guides our path to fully realizing the game-changing potential of nuclear energy as an essential element of future energy systems with net-zero carbon emissions. INL envisions secure, resilient net-zero energy systems integrating the power of clean, reliable nuclear energy and other firm power sources with intermittent renewables, while repurposing heat and electricity for direct use and to support industrial processes, such as hydrogen generation.

"INL can change the world's energy future by being bold, innovative, and deliberate in our thoughts and actions, and by focusing on outcomes that matter. We will dream big, execute, collaborate, and be receptive to change."

INL's five strategic science and technology (S&T) initiatives drive our work toward this net-zero energy future. Our nuclear reactor sustainment and expanded deployment initiative is focused on nuclear energy generation and continues to support the existing fleet, while leading research and development (R&D) for the advanced reactor technologies poised for deployment over the next 5 to ten years. Integrated fuel cycle solutions ensure that the clean, reliable energy generated by nuclear reactors will be powered by a fuel cycle that is safe, secure, and economical from inception to disposition. INL works to advance integrated energy systems to transition to net-zero and is prepared to demonstrate how a nuclear power plant can be integrated with other forms of clean generation to stabilize the grid, produce reliable and economical electricity, and produce industrial hydrogen and other products.

Advanced design and manufacturing for extreme environments efforts secure manufacturing processes to produce materials solutions with the properties required for the extreme and harsh operating conditions of future reactors, elements of the fuel cycle, integrated energy systems components, and defense applications. INL will continue to demonstrate national leadership in secure and resilient cyber-physical systems by developing and deploying transformational all-hazards solutions across U.S. critical infrastructures.

John Wagner
Director, Idaho National Laboratory

Combined, these five initiatives are a roadmap toward making the secure, resilient, net-zero energy future a reality.

INL is committed to leading by example, by aligning our clean energy research, development, and demonstration (RD&D) mission activities with our operations to become a national carbon neutral prototype and achieving net-zero emissions on the INL Site within the next 10 years. Achieving net-zero means drastically reducing on-site emissions and offsetting the limited residual emissions from activities that are impossible to decarbonize. Working with partners, INL will demonstrate and deploy advanced nuclear reactors, grid integration, transportation electrification, improved electricity storage, and other elements of a clean, integrated energy system at scale.

Changing the world's energy future is an audacious goal, but one that is necessary to mitigate climate change while also addressing global energy poverty. INL is up for the challenge and prepared to leverage its exceptional people, unique infrastructure, and world-class facilities to deliver on its vision. This 2021 Laboratory Overview contains details about how INL's research, development, demonstration, and deployment (RDD&D) activities will innovate clean energy solutions and robust critical infrastructure protections on behalf of our fellow citizens.

INL FY20 SNAPSHOT

As the U.S. leader for advanced nuclear energy RD&D, INL applies an unmatched combination of unique test bed facilities and world-leading technical expertise to execute its mission to discover, demonstrate, and secure innovative nuclear energy solutions, other low-carbon energy options, and critical infrastructure. Climate change is one of the most urgent and challenging economic and national security issues confronting our nation today. INL is addressing this challenge by combining basic research, applied science and engineering, and problem-solving to pursue our vision to change the world's energy future and secure our nation's critical infrastructure.

INL leads RD&D across five S&T initiatives. Secure, resilient, integrated low-carbon energy systems will enable a net-zero carbon emissions future. Next-generation energy systems will integrate the baseload power of nuclear energy and other clean baseload sources with intermittent renewables and repurposed heat and electricity from existing reactors for direct use and to support industrial processes such as hydrogen generation. To realize this future, INL ensures that, in the short term, our nation's fleet of nuclear reactors remains safe and effective while developing and deploying the next generation of reactors, supported by a safe, secure, and economical advanced fuel cycle.

Concurrently, INL is developing effective and economical approaches to integrate nuclear and other sources of clean energy in new ways that directly support industrial manufacturing while strengthening grid security and reliability. Work in advanced design and manufacturing supports these technological advances while secure and resilient cyber-physical systems protect U.S. civilian and defense infrastructures, including the infrastructures of future integrated energy systems, against natural and human threats. With foundational core capabilities grounded in a legacy as the nation's nuclear energy laboratory and extensive multiprogram assets strategically deployed to take advantage of an 890-square-mile Site, INL is uniquely prepared to lead the development and demonstration of the integrated net-zero energy systems of the future.

INL pursues its mission through collaborative partnerships with federal entities, other national laboratories, international organizations, universities, and private industry. INL's robust partnerships are essential to accelerating time to market for research breakthroughs, supporting American competitiveness and building a clean energy future.

INL is managed by BEA, for the DOE-NE. BEA is a partnership of Battelle, BWX Technologies Inc., Amentum (formerly AECOM), the Electric Power Research Institute (EPRI), and the National University Consortium of Massachusetts Institute of Technology, the Ohio State University, Oregon State University, North Carolina State University, the University of New Mexico, and university collaborators from the state of Idaho (the University of Idaho, Idaho State University, and Boise State University).

EXCELLENCE
We do our best work every day

INCLUSIVITY
We commit to building an empowered workforce that's inclusive and diverse; where everyone feels they belong

INTEGRITY
We demonstrate honesty, professionalism and equity in every decision and action

OWNERSHIP
We take pride, accountability and responsibility for actions that drive laboratory success

TEAMWORK
We treat others with dignity and respect and promote collaboration

SAFETY
We demonstrate world leading safety behaviors and safety performance, while accomplishing the mission

305 DOE-owned buildings & trailers

35 Contractor-leased buildings & trailers

12 Hazard Category II & III non reactor facility/activities

50 Radiological facilities

4 Operating reactors

5,200+ Employees

3 Fire stations

40 Miles of primary roads/ 125 total miles of road

17.5 Miles of railroad for shipping nuclear fuel

1 Museum

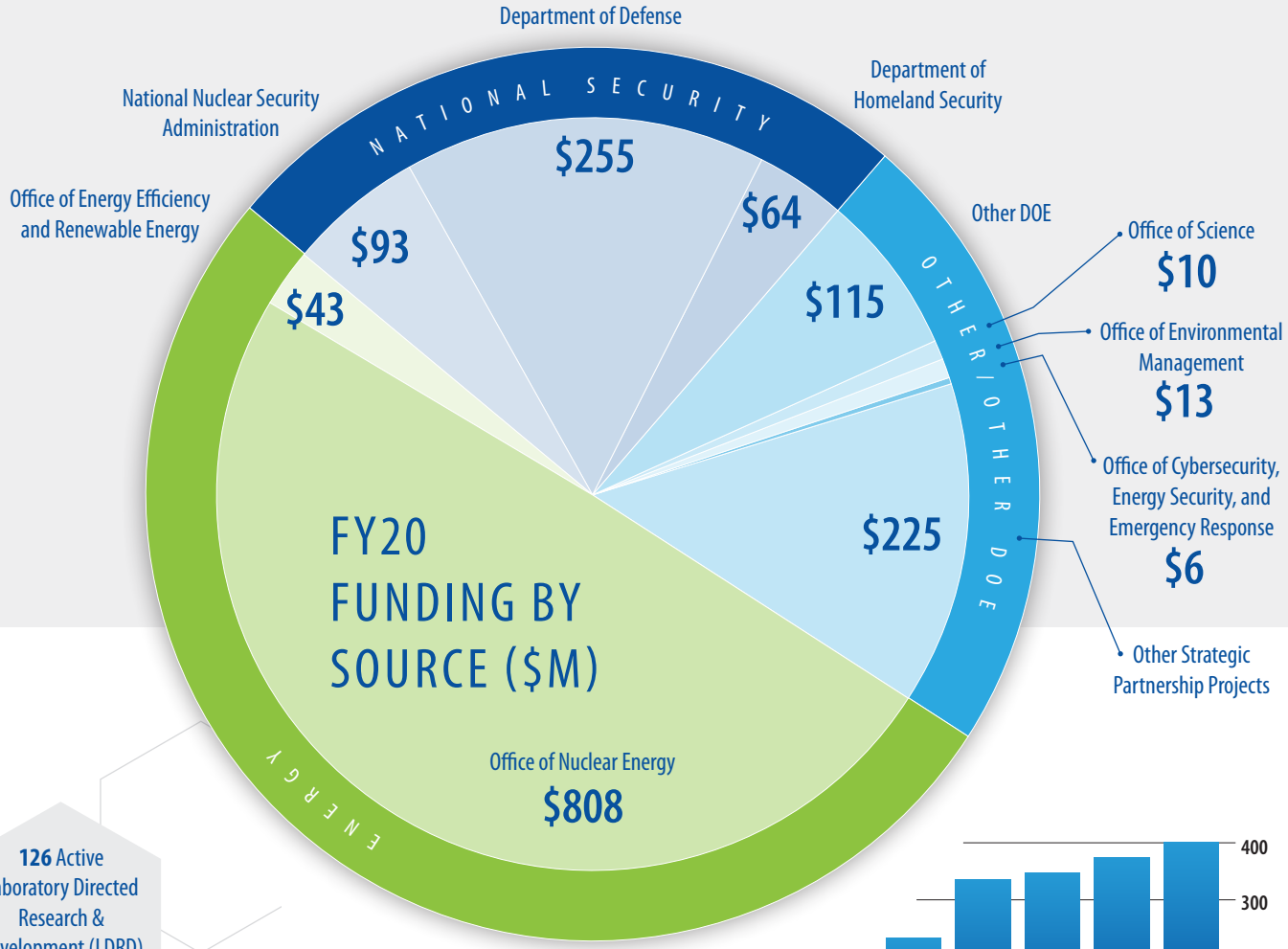
112 Miles of high-voltage transmission lines

7 Substations with interfaces to two power providers

All metrics presented in this documents are for fiscal year (FY) 2020.

569,135 Acres
889 Square Miles

INL's Geography, Infrastructure, Sites, and Facilities Enable Energy and Security Research, Development, and Demonstration at Scale



126 Active Laboratory Directed Research & Development (LDRD) Projects

Interns, postdocs, and graduate fellows from **46 states** and **32 countries**

7 Active distinguished postdocs

511 New Hires

$2.88B economic impact on the state of Idaho

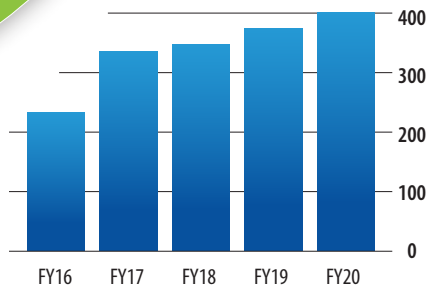
13 Postdocs transitioned to staff

FY20 operating cost

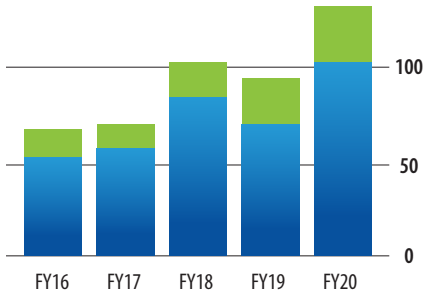
- DOE/National Nuclear Security Administration Costs: $1,088M
- Strategic Partnership Projects (No t from DOE or Department of Homeland): $334M
- Cooperative Research and Development Agreements: $7M
- Department of Homeland Security Costs: $64M
- **Total: $1,492M**

FY20 human capital

- 5,200+ full-time equivalent employees
- 38 joint appointments
- 67 postdoctoral researchers
- 280 undergraduate interns
- 189 graduate interns
- 605 facility users
- 31 visiting scientists



Total Active Licenses



Innovation Disclosures

Total Invention Disclosures
Total Software Disclosures

INL'S STRATEGIC S&T INITIATIVE OVERVIEW

INL's S&T initiatives will change the world's energy future and secure our critical infrastructure

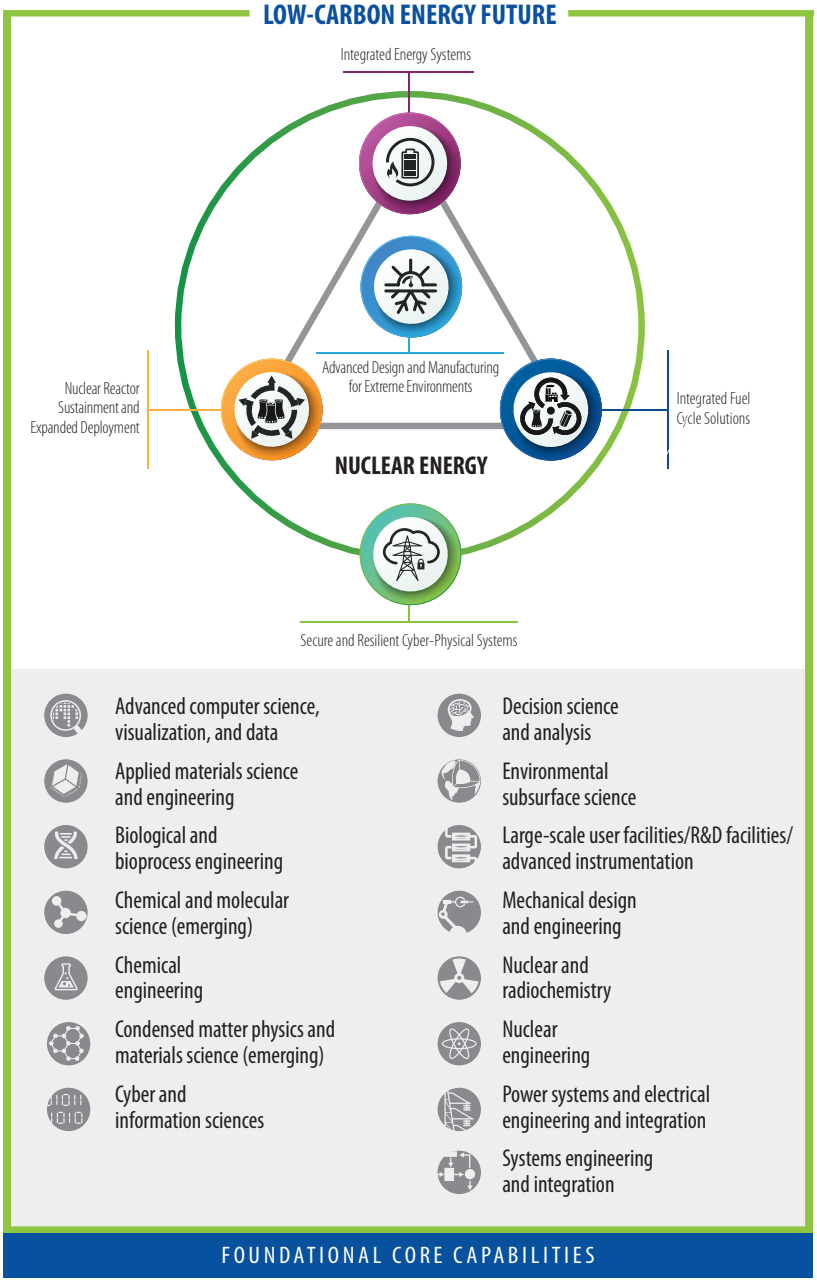
INL uses its world-leading facilities, specialized equipment, and expert teams of people to support DOE missions across 15 of the DOE-designated core capabilities. These capabilities represent a unique science and engineering skill set spanning the continuum from basic and applied research to development, demonstration, and validation of technologies at scale, speeding deployment.

INL leverages these capabilities to deliver S&T outcomes through its five initiatives: nuclear reactor sustainment and expanded deployment, integrated fuel cycle solutions, integrated energy systems, advanced design and manufacturing for extreme environments, and secure and resilient cyber-physical systems. INL prioritizes integration and collaboration across its core capabilities to maximize the potential of all five initiatives. The laboratory maintains and enhances its existing and emerging core capabilities to expand INL's RD&D leadership and the impact of its S&T innovation.

Nuclear Reactor Sustainment and Expanded Deployment. INL develops and demonstrates advanced technologies to improve the performance of both existing and future carbon-free, reliable nuclear energy systems that are vital to achieving net-zero carbon emissions.

Integrated Fuel Cycle Solutions. INL advances effective and integrated fuel cycle solutions to sustain the current reactor fleet and enable its expansion and replacement with advanced reactors.

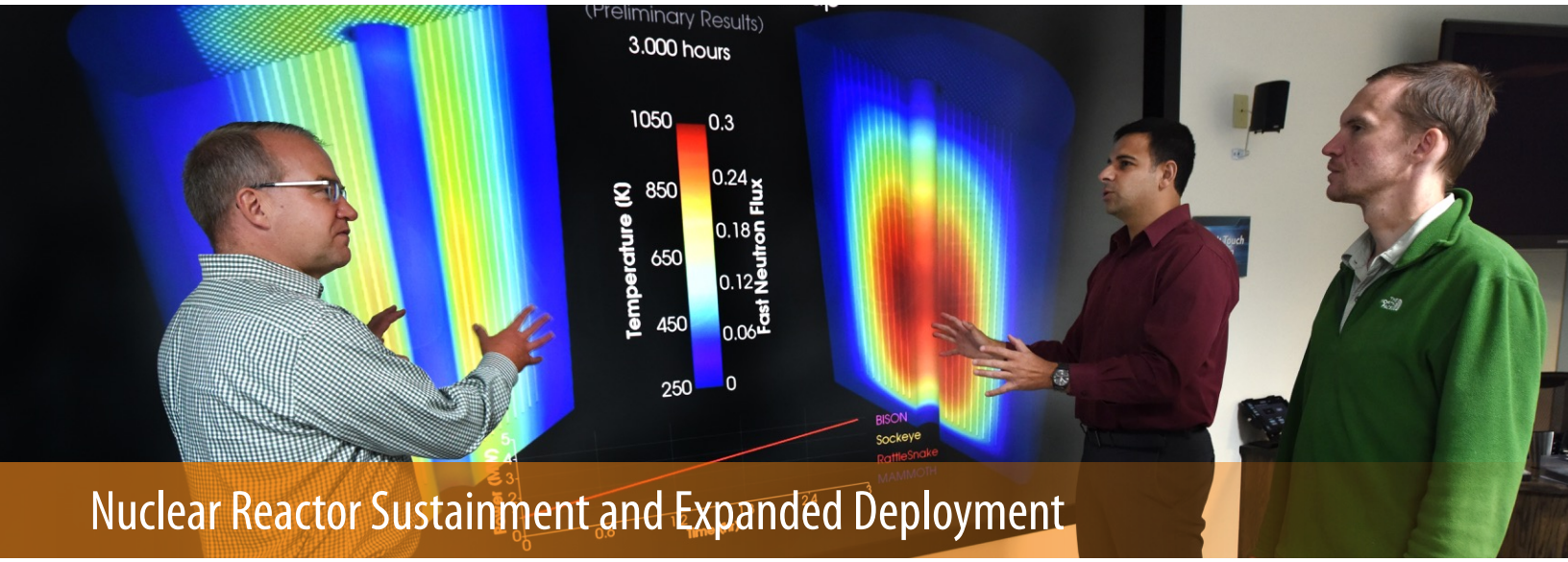
Integrated Energy Systems. INL leads the discovery and demonstration of innovative technologies to advance the integration of energy generation, storage, and delivery needed for a low-carbon future.



Advanced Design and Manufacturing for Extreme Environments. INL accelerates discoveries to improve the performance of materials for harsh and extreme environments, including advanced nuclear reactors, defense systems, and space applications, while reducing costs and production time.

Secure and Resilient Cyber-Physical Systems. INL uses its world-class R&D capabilities and unique assets to solve complex challenges to the security and resilience of our infrastructure, including emerging threats and vulnerabilities.

Collectively, these five S&T initiatives propel INL's world-class science, people, and facilities to pursue the RD&D innovations that will build our net-zero energy future.



Nuclear Reactor Sustainment and Expanded Deployment

High performance computing and advanced modeling and simulation capabilities help engineers make reactors safer, more reliable, and more cost efficient.

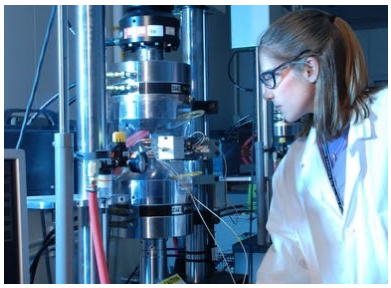
Leading Sustainment of the Current Nuclear Reactor Fleet and Accelerating Deployment of Advanced Reactors

The energy provided by nuclear reactors is essential to meeting the world's low-carbon energy goals. Highly efficient nuclear plants, operating 24/7 through a range of weather conditions at a more than 93% average capacity factor, are an essential complement to wind, solar, fossil fuels with carbon capture and storage, and energy storage solutions as the United States develops and implements its strategies to reach net-zero carbon emissions. To achieve this net-zero future, it is essential to sustain and extend the safe and economical operational life of the current fleet while concurrently expanding the fleet of the future through the RD&D needed to commercialize advanced reactors.

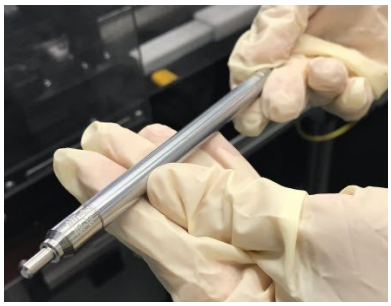
INL's strategic nuclear RD&D infrastructure includes irradiation testing capabilities at the Advanced Test Reactor (ATR) Complex and Transient Reactor Test (TREAT) facility essential for developing the materials and fuels technologies that support current reactors and advanced reactor development. INL's strategic infrastructure and strategic partnerships with industry and other stakeholders will create and define the next phase of global nuclear energy by driving technological innovations and operational advances through proof of concept, proof of performance, and proof of operation.

Nuclear reactor sustainment and expanded deployment advances foundational science, at-scale demonstrations, technology validation, and strategic partnerships to:

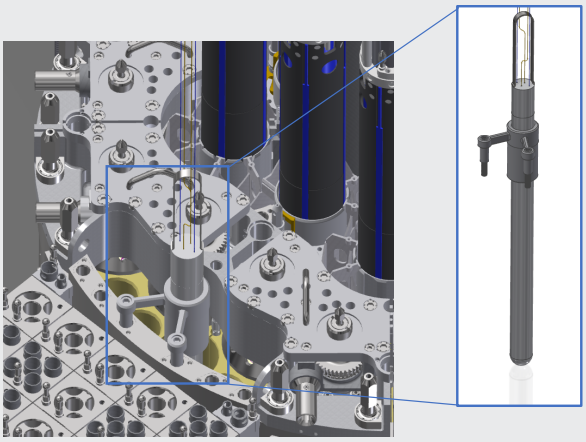
1. Strengthen the domestic commercial nuclear energy enterprise.
2. Enable U.S. technological leadership in global nuclear energy markets.
3. Expand and deploy national nuclear energy strategic infrastructures.



Researchers are accelerating discovery, development, and qualification of new nuclear materials.



INL is developing and testing accident tolerant fuel concepts in partnership with industry.



LDRD SUCCESS STORY

LDRD investments continued to grow INL capabilities in FY20. Through LDRD, researchers steward and expand INL's experimental capabilities, increasing the lab's ability to execute advanced nuclear energy research. A project led by Abdalla Abou-Jaoude, who joined INL as a distinguished postdoctoral researcher, demonstrated the feasibility of a salt irradiation loop in the ATR, laying the groundwork for next-generation irradiation testing at ATR.

A computer aided design illustration of the Versatile Experimental Salt Irradiation Loop experiment assembly inside the ATR.

Powering the Mars 2020 rover, and beyond

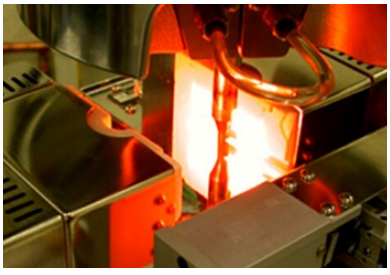
INL assembled, tested, and partnered with the National Nuclear Security Administration on transportation and radiological contingency planning for the Multi-Mission Radioisotope Thermoelectric Generator that powers the National Aeronautics and Space Administration (NASA) Mars Perseverance rover. Multi-Mission Radioisotope Thermoelectric Generators are ideal for space missions because they are compact, durable, and reliable, providing continuous power over long periods of time. The generators consist of two major elements: a heat source that contains plutonium-238 and thermocouples that convert the plutonium's decay heat energy in the cold of space to electricity.

INL plays a crucial role in providing radioisotope power systems to NASA, and ATR continues to expand available positions for plutonium-238 production to support increasing NASA missions. INL is expanding its research to include the nuclear thermal propulsion and fission surface power applications that will be needed for eventual crewed missions to Mars.

Vibration testing simulates launch conditions by mounting the radioisotope thermoelectric generator on a vibration table that creates proto-flight test environments.

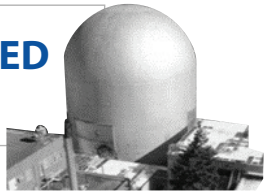
FY20 IMPACT

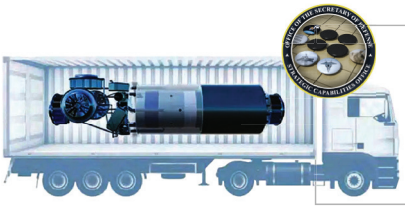
The American Society of Mechanical Engineers (ASME) publishes "ASME Boiler and Pressure Vessel Code" that lays out design rules for how much stress is acceptable and specifies the materials that can be used for power plant construction. In FY20, following years of effort, researchers from INL, Argonne National Laboratory, and Oak Ridge National Laboratory helped qualify Alloy 617 as the first new material accepted into the ASME Code in 30 years. Alloy 617, a combination of nickel, chromium, cobalt, and molybdenum, can be used in advanced nuclear reactor designs because it allows higher temperature operation. Inclusion of Alloy 617 in the ASME Code provides designers working on new high temperature nuclear power plant concepts with 20% more options for component construction materials.



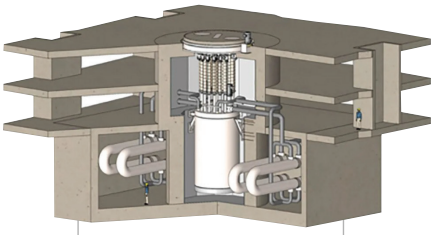
Alloy 617 was subjected to extensive testing including fluctuations in temperature and physical stress before becoming the first new material added to the ASME Code in 30 years.

DOME TEST BED
2023-2024 | NRIC

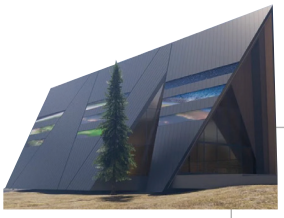




PROJECT PELE MICROREACTOR
2023-2024 | DOD



HERMES
2026| KAIROS



AURORA
TBD | OKLO

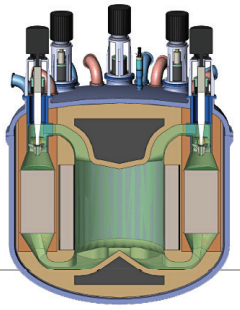
MARVEL
2023 | DOE

2026

2025

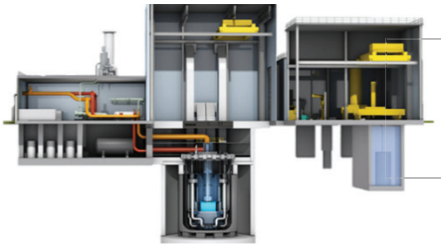
2024

2023



MCRE
2025 | SOUTHERN CO. & TERRAPOWER

LOTUS TEST BED
2024-2025 | NRIC



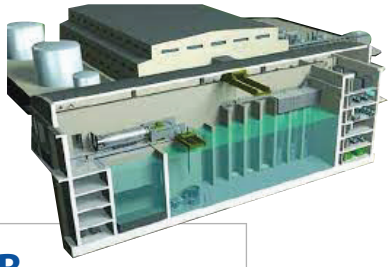
NATRIUM REACTOR
2028 | TERRAPOWER & GE

2030

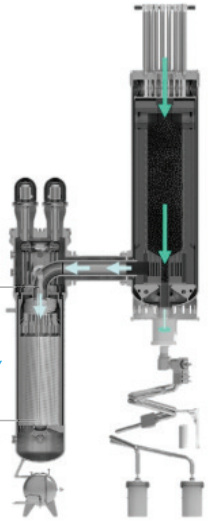
2029

2028

2027



VOYGR
2029 | UAMPS & NuScale



Xe-100
2027 | X-ENERGY

Accelerating advanced reactor development, demonstration, and deployment

The United States is poised to lead the decarbonization of global energy networks through advanced reactor development, demonstration, and deployment. INL, as the nation's nuclear energy laboratory, is partnering with other government agencies and the private sector to achieve success on an ambitious timeline.

Integrated Fuel Cycle Solutions

The hybrid zirconium removal prior to extraction (ZIRCEX) process enables high-assay, low-enriched uranium (HALEU) production from federally owned fuels.

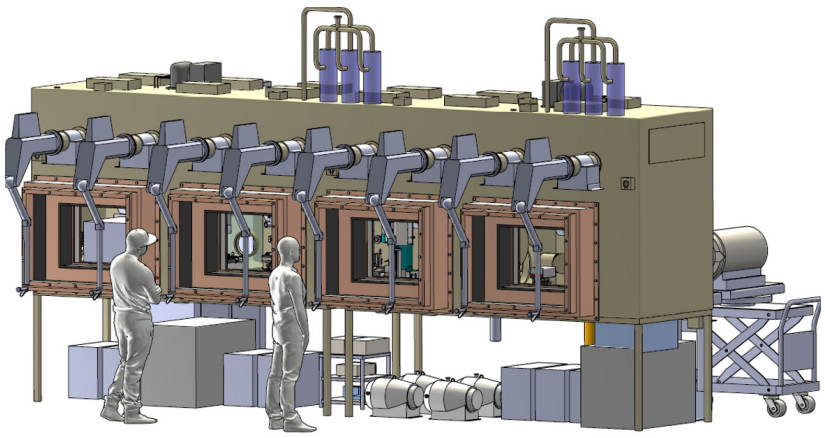
Developing Integrated Fuel Cycle Solutions

The future of nuclear energy requires effective and integrated fuel cycle solutions to sustain the current reactor fleet and enable its future replacement and expansion with advanced reactors. INL's integrated fuel cycle solutions initiative supports the safe, secure, and economical management of nuclear fuel from inception to disposition.

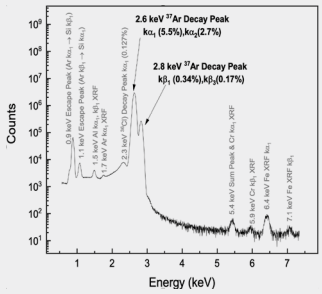
The next-generation integrated fuel cycle starts with available special nuclear materials to support the fuel fabrication needs of advanced reactors. New fuel cycle technologies extend to the management and disposition of existing and future radiological waste materials. Proliferation risk reduction will be built into the advanced reactor integrated fuel cycle through simplified used nuclear fuels recycling processes, real-time interrogation of used nuclear fuels treatment processes, and direct chemical and physical immobilization options for used nuclear fuels and other irradiated materials.

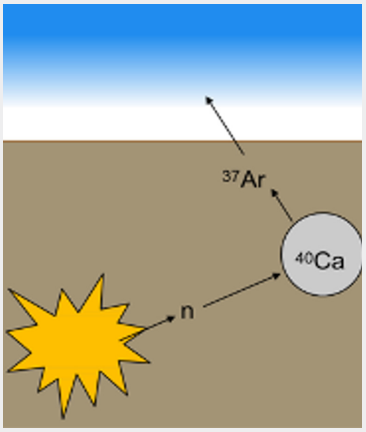
Integrated fuel cycle solutions advance:

1. Availability of special nuclear materials and strategic isotopes.
2. Management of radiological waste materials and used nuclear fuels.
3. Proliferation risk reduction.
4. Development of RD&D test beds.



Developing the Molten Salt Thermophysical Examination Capability will provide data needed to design, demonstrate, license, and operate a molten salt reactor.





LDRD SUCCESS STORY

The detection of argon-37 above background levels is a clear and unique indicator of the underground detonation of a nuclear device. Through LDRD, researchers collaborated with the Idaho Accelerator Center to demonstrate the ability to produce high quality samples of standard argon-37 to enhance treaty verification.

A LDRD project improved global capabilities to establish evidence of an underground nuclear explosion by better understanding the energy spectrum of chemically separated argon produced through irradiation.

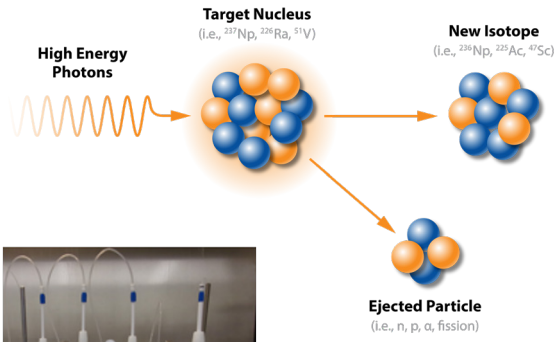
Supporting the development and deployment of the U.S. high-assay, low-enriched uranium (HALEU) fuel cycle

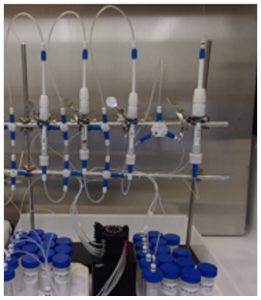
INL enables the deployment of advanced reactors by providing an interim supply of HALEU from recovered and downblended highly enriched uranium from current Experimental Breeder Reactor-II (EBR-II) spent nuclear fuel stocks. This supports advanced reactor developers and aligns with INL's commitments to the state of Idaho, specifically the stabilization of EBR-II fuel by 2028 and disposition of waste by 2035. EBR-II metal HALEU is directly suitable as a fuel feedstock for fast spectrum reactors, but it contains chemical impurities and radioactive contamination that preclude its immediate use as a fuel feedstock for thermal spectrum reactors. To address the variety of fuels required for demonstrations (metals, oxides, thermal, and fast spectrums), INL is conducting a polishing campaign to produce material that meets thermal spectrum specifications for recovered materials. This is accomplished in collaboration with Pacific Northwest National Laboratory and Argonne National Laboratory scientists.

INL produces uranyl peroxide, uranium trioxide, and uranium oxide and removes impurities to support thermal spectrum fuel fabrication needs.

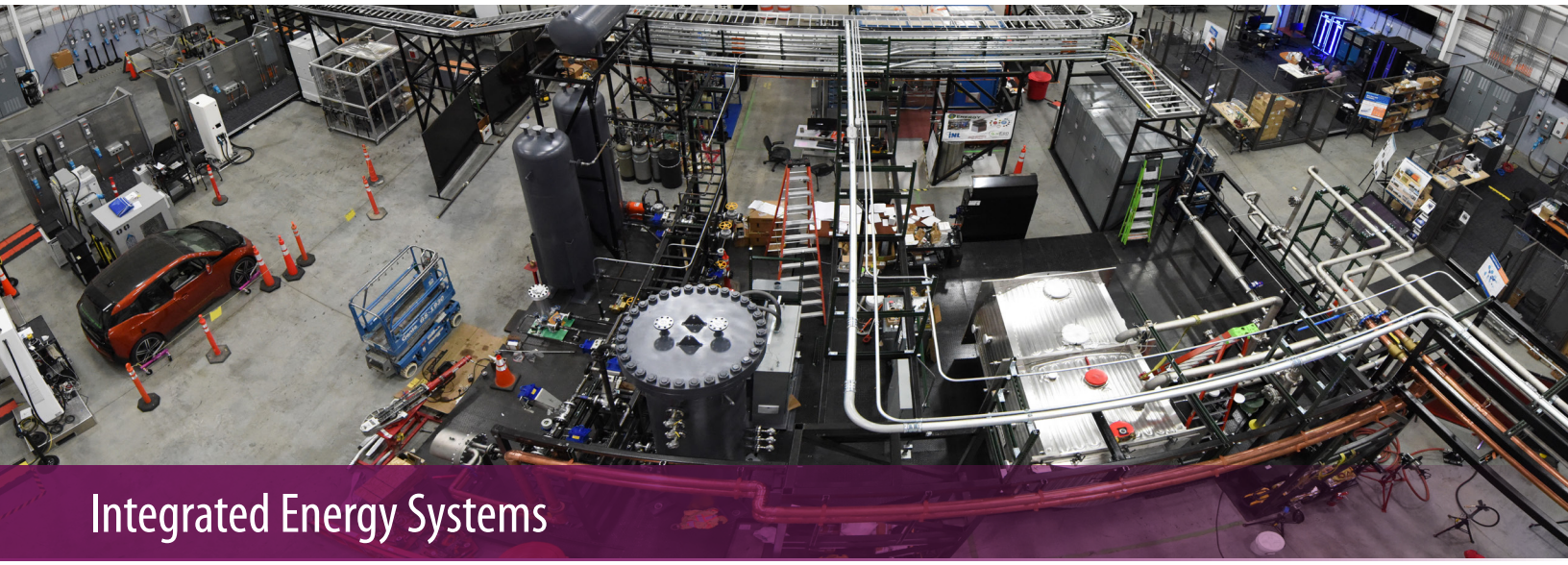
FY20 IMPACT

Actinium-225, neptunium-235 and -236, plutonium-236, and short-lived, low yield fission product isotopes are critical to nuclear science research areas ranging from advanced nuclear fuels development to astrophysics and fundamental nuclear science. Actinium-225 and scandium-47 are needed for new and improved cancer treatments. INL researchers investigated new photonuclear production pathways in combination with novel, rapid chemical separations methods to make these radioisotopes available on demand, in larger quantities, at significantly lower cost, and with less radiation exposure than previously possible.





INL developed novel ways to produce rare isotopes needed for research, security, and medicine.



Integrated Energy Systems

INL has invested in new facilities and equipment in its Energy Systems Integration Laboratory.

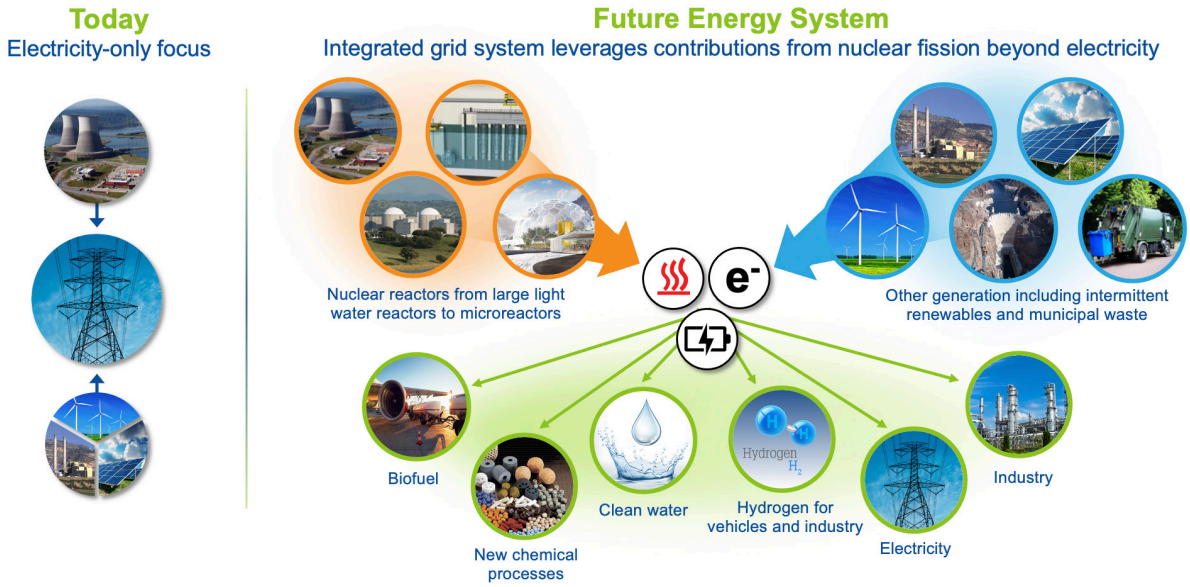
Advancing Integrated Energy Systems to Transition to Net-Zero

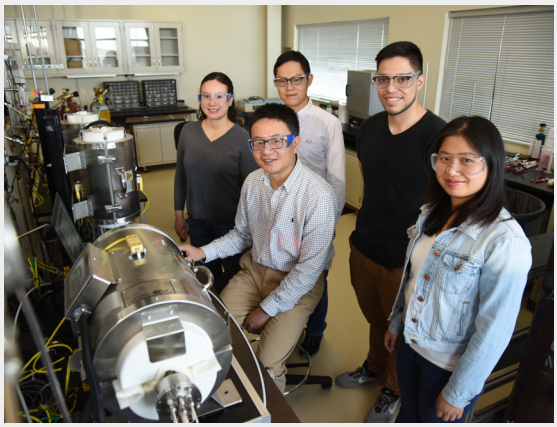
INL leads research needed to realize the sustainable and competitive low-carbon integrated energy systems of the future, pursuing innovations across generation, delivery, storage, and end use.

Nuclear energy is a proven low-emission option that can reliably meet electricity demands, but its potential value extends far beyond electricity generation. Nuclear energy is the only large-scale, low-emission energy option that provides both heat and electricity without requiring massive energy storage. To capitalize on the opportunities beyond baseload electricity generation, INL's integrated energy systems initiative leverages INL's core capabilities for RD&D of multigeneration energy systems that incorporate nuclear energy with other forms of electricity generation to provide new products, such as hydrogen, while increasing grid reliability, resilience, and affordability.

To ensure technical and economic feasibility, and the eventual successful deployment of integrated system solutions, INL efforts focus on:

1. Demonstrating high efficiency thermal energy use.
2. Enabling a sustained, resilient, and reliable clean energy grid.
3. Developing novel chemical processes using low-emissions energy.
4. Enhancing tools and approaches to optimize integrated energy systems operations.





LDRD SUCCESS STORY

Dong Ding and his team created a novel multiscale computational framework to guide development of advanced solid oxide electrochemical membrane reactors, with a special emphasis on the case of co-production of ethylene and chemicals using ethane and carbon dioxide as the feedstocks at intermediate temperatures. The LDRD project used the heat and electricity from nuclear energy and renewables as energy inputs.

Dong Ding with interns on his research team (before the COVID-19 pandemic).

Leading development and demonstration of the use of nuclear energy beyond the electric grid

INL leads the DOE cost-shared projects awarded to Exelon and a tri-utility team that includes Energy Harbor, Xcel Energy, and Arizona Public Service. These projects will demonstrate hydrogen production at multiple light water reactor plants in the current United States fleet using both electrically driven low temperature electrolysis technology (Exelon, Energy Harbor) and thermally and electrically driven high temperature electrolysis technology (Xcel Energy). Future work is being considered to demonstrate larger-scale systems in collaboration with Arizona Public Service.

These projects will simultaneously raise the readiness of hydrogen generation technologies, while also providing a sound basis for the country to implement and scale up hydrogen production to a level that will have the desired impact on national energy security and climate change. This strategic partnership is a model for accelerating disruptive technology innovations and systems integration to commercial pilot demonstrations.

INL is partnering with industry to produce hydrogen for first movers of clean hydrogen: fuel-cell buses, heavy-duty trucks, forklifts, and industrial users.

FY20 IMPACT

Electric vehicle bus manufacturer New Flyer partnered with INL to test a state-of-the-art bus capable of high-power charging. Researchers charged New Flyer's Xcelsior transit bus using a 350-kilowatt high-power charging station at the Electric Vehicle Infrastructure Laboratory in Idaho Falls and conducted tests to quantify the performance of both the bus and the charger. Charging time was just one metric INL researchers evaluated to learn more about how high-power charging might work with tomorrow's fleet of medium- and heavy-duty electric vehicles. Researchers also looked at charging efficiency, power quality, communications compatibility between the vehicle and charger, and cybersecurity robustness and resiliency. Proof of concept of high-power charging for buses is an important step toward businesses and municipalities adopting electric vehicle fleets.

This 60-foot New Flyer bus, the first of its kind capable of high-power charging, traveled to INL under its own power and participated in a high-power charging test.

Advanced Design and Manufacturing for Extreme Environments

INL is installing prototype advanced manufacturing systems to scrutinize processes in situ while building components.

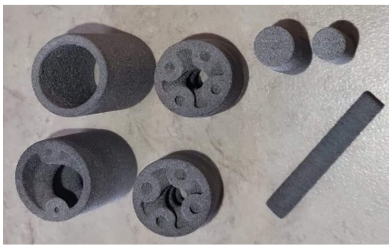
Improving Design and Manufacturing of Materials for Extreme Environments

Nuclear, aerospace, transportation, defense, and other energy systems expose components to extreme or harsh environments, including high-radiation fields, temperature extremes, corrosive species, chemical containment, dynamic loading, mechanical impact, and both vacuum and high-pressure atmospheres. INL's advanced design and manufacturing for extreme environments initiative uses the laboratory's core capabilities to accelerate discoveries and advances in process-informed design and advanced manufacturing to support the materials needs of extreme environments. This initiative is a catalyst for cross-initiative coordination and collaboration. It leverages expertise and capabilities developed to increase the performance and economic competitiveness of the needed processes and materials to achieve the goals of other initiatives.

INL leverages its experience and expertise in extreme environments to conduct RD&D that yields better materials while shortening the product cycle. INL identifies novel feedstocks and designs manufacturing processes with targeted microstructures and performance characteristics built into the materials and components. The next step is advancing the coupling of real-time modeling and simulation with manufacturing to allow for rapid prototyping and component development. Finally, INL works on intensifying and scaling up design and manufacturing tools and technologies to demonstrate effectiveness at production scale.

INL's research focuses on three interconnected areas:

1. Accelerate process discovery and development using process-informed design.
2. Enable the integration of secure digital design and manufacturing.
3. Demonstrate intensified and scaled-up advanced manufacturing processes.



In partnership with Advance Cooling Technologies Inc., INL produced porous metal materials for use in heat pipes.

LDRD SUCCESS STORY

INL researchers successfully tested and installed a crystal growing system that will enable the growth of single crystal materials for production of specifically doped optical materials. The system will also facilitate the growth of bulk single crystal nuclear materials that can be used in more accurate thermophysical properties measurements that eliminate the convolution of phonon scattering. These highly specialized crystals can be incorporated into instruments to provide high-performance in-pile power measurement for nuclear reactors and accurate thermophysical property measurements to support modeling and simulation.

INL's crystal growing system (left) and an example of the single crystal materials it produces (right).

Developing new manufacturing capabilities

INL is installing a large-scale, direct current spark plasma sintering (SPS) machine. The 800-ton direct current sintering machine represents the world's largest system of its kind and can process various materials, including super hard ceramics that are difficult to scaleup and other rigid materials ideal for operations in harsh and extreme environments. When fully operational, this SPS machine will support discovery and experimental validation of first-principles phenomena to enable design and engineering through modeling and simulation. This system could revolutionize the production scale of specialized materials, enabling at-scale pieces to be manufactured affordably.

INL's DC-800 SPS machine, the world's largest, will expand SPS capabilities into industrial-scale applications.

FY20 IMPACT

In 2019, INL began using SPS to manufacture advanced reactor fuels for NASA's nuclear thermal propulsion program. INL additively manufactured nuclear fuel systems components using gadolinium-doped depleted uranium dioxide pellets for anti-hourglassing.

Manufactured composite fuel forms for NASA using SPS.

Secure and Resilient Cyber-Physical Systems

Radiological and other first responder training opportunities help public and private entities enhance resilience and manage risk.

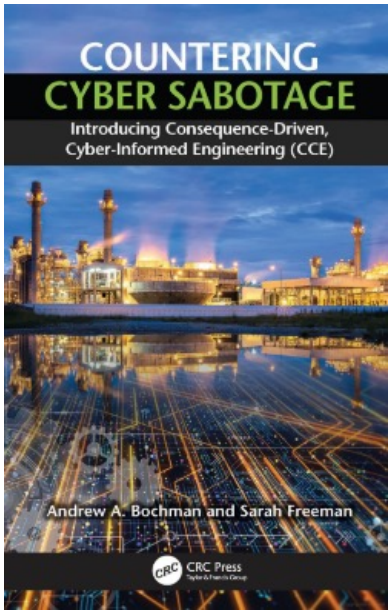
Leading Transformational Technological Advances for Secure and Resilient Cyber-Physical Systems

The cyber-physical systems integral to U.S. civilian and defense infrastructure depend on transformational technological advancements to protect against sophisticated adversaries. Solutions must integrate traditional information assurance methods with the controllability, reliability, and safety of physical processes, while resiliently managing the interdependencies of complex, engineered systems. Through the secure and resilient cyber-physical systems initiative, INL develops, models, and validates at scale the new cyber-informed engineering methods, robust infrastructure analysis, and intelligent technologies for instrumentation and control. INL's comprehensive approach relies on its core capabilities to incorporate technology, processes, and people to address the nation's most critical challenges to secure and defend vital U.S. cyber-physical systems. INL's capabilities to conduct both unclassified and classified work using its unique facilities and interdisciplinary approach enrich its solution sets.

INL is expanding the nation's only multiscale critical infrastructure test bed.

INL's efforts to advance secure and resilient cyber-physical systems center on four areas:

1. Cyber-informed science and engineering across all initiatives.
2. All-hazard critical infrastructure resilience through the INL Resilience Optimization Center.
3. Enduring control systems cybersecurity innovation.
4. Wireless and spectrum security through the Wireless Security Institute.

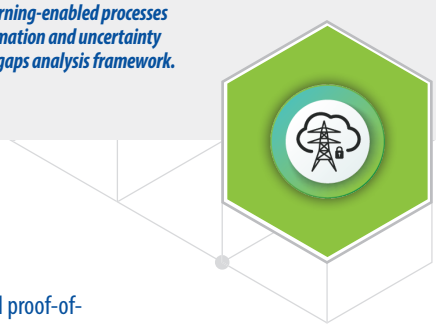


Researchers published a book on INL-developed Consequence-driven, Cyber-informed Engineering, outlining principles to shape an organization's resistance to and recovery from cyber-physical risk.

LDRD SUCCESS STORY

INL's All-hazards Analysis software provides a framework and a methodology for mapping the relationships among vital and vulnerable assets. What started as an LDRD project has blossomed into a continually evolving platform supporting a wide spectrum of resilience research, continuity of operations planning, and disaster response.

All-hazards Analysis uses machine-learning-enabled processes to integrate facility and systems information and uncertainty measures into a decision support and gaps analysis framework.



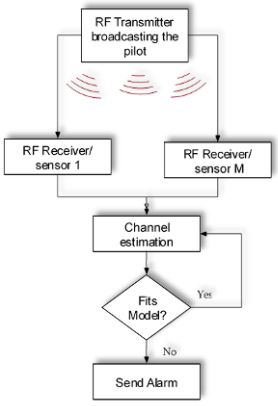
Assisting with the national strategy to secure fifth generation mobile networks (5G)

INL has built a team from multiple institutions to provide S&T inputs to the U.S. departments of Defense, Homeland Security, and Justice in addition to DOE. This includes participation in key advisory panels and task forces, such as the White House Office of Science and Technology Policy's Wireless Spectrum Research and Development Interagency Working Group and Office of Undersecretary of Defense Research and Engineering 5G Initiative. INL is expanding its initial 5G research lab-scale assets to industry-scale environments as technology becomes available. INL provides an independent technical validation authority for secure implementation and environment sensing capabilities. This is part of a long-term strategic plan to transform INL's Wireless Test Bed into a nationally recognized 5G Test Range.

INL researchers are ensuring secure and resilient wireless devices, networks, and spectrum, for 5G and beyond.

FY20 IMPACT

Researchers conducted the initial proof-of-principle to show that a radio frequency (RF) sensor network within a cabinet full of equipment can detect attempts to gain access to the inside of the cabinet. The results have applications related to safeguarding the monitoring cabinets deployed by DOE and the International Atomic Energy Agency for nuclear compliance.



Researchers developed novel sensor technology to detect intrusion and hacking of nuclear treaty compliance systems.

NET-ZERO INL

Demonstrating the Path Forward to a Clean Energy Economy and a Net-Zero Energy Future

INL is committed to achieving net-zero carbon emissions by 2031. Achieving net-zero requires an innovative, flexible, and adaptive strategy and action plan. This new strategy must go above and beyond what INL has already achieved over the past decade. Reaching net-zero in 10 years will be accomplished by incentivizing staff behaviors, developing an aggressive carbon reduction strategy and action plan, accelerating RD&D of renewable and thermal energy technologies, increasing consumption of clean energy, and continued infrastructure transformation. Over the next several years INL actions will include:

- Develop, publish, and align operations and research to a net-zero carbon emissions plan.
- Work with other national labs to establish a comprehensive scorecard.
- Implement key projects leveraging INL mission RD&D.
- Champion an equitable, inclusive net-zero community through outreach and engagement.
- Invest strategically in technology, process upgrades, building upgrades, supply chain development, and culture change.

This audacious net-zero goal aligns with INL's vision and mission, and with DOE priorities.

INL will lead by example demonstrating technology innovations that will change out energy future.

Zero Emission Vehicle Transit System Demo

305
Total vehicles

5,200+
Employees

320
DOE-owned buildings and trailers

27.3
Megawatts purchased in FY20

SCOPE

1 Greenhouse gas (GHG) emissions from sources owned or controlled by DOE

Mobile combustion | Onsite landfill | Onsite wastewater treatment | Fugitives and refrigerants | Stationary combustion

2 GHG emissions resulting from the generation of electricity, heat, or steam purchased by DOE

Purchased electricity | Transmission and distribution loss-owned | Renewable energy certificates* (RECs)

3 GHG emissions from sources not owned or directly controlled by DOE but related to INL activities

Employee commuting | Business travel (air and ground) | Contracted wastewater treatment | Transmission and distribution loss-shared

** Although RECs are included, we do not intend to use or purchase them to achieve our net-zero goal.*

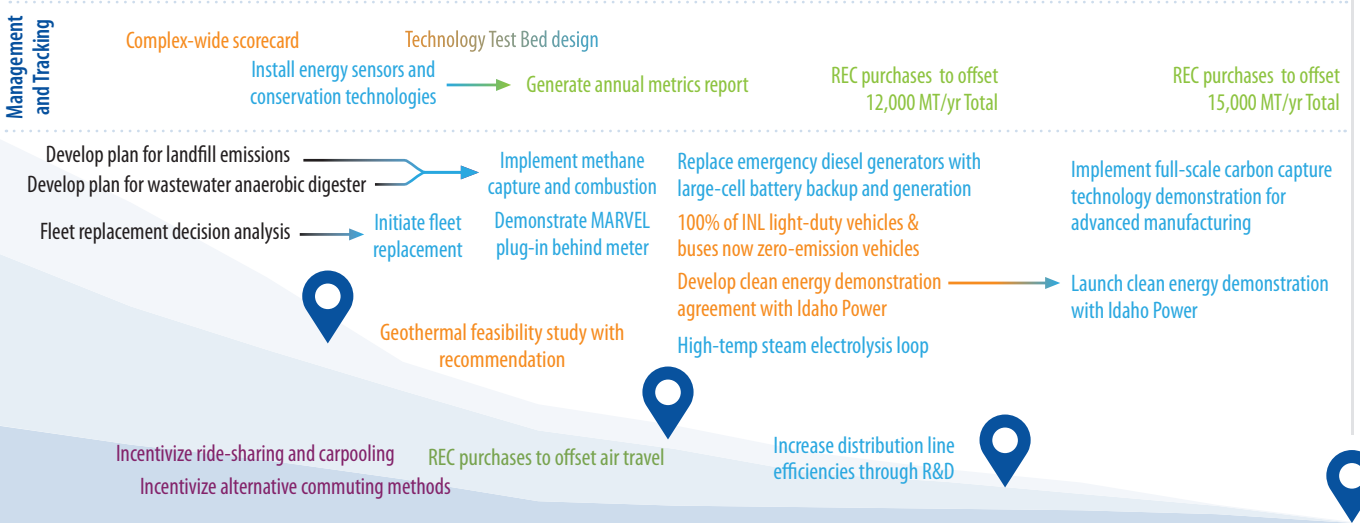
A variety of innovative technology demonstrations at INL will help the laboratory achieve its net-zero goal.

Strategic Approach

- **Avalanche Method: Tackle largest contributors first**
- **Minimize reliance on RECs**
- **Lead the way: Demonstrate new technologies where possible**

Goals and Milestones

2022: Complex-wide scorecard
2024: Install energy sensors and conservation technologies
2024: Implement a Technology Test Bed
2025: Achieve 75% reduction and 2031: 100% reduction



INDUSTRY PARTNERSHIPS

Maximizing Impact through Strategic Engagement

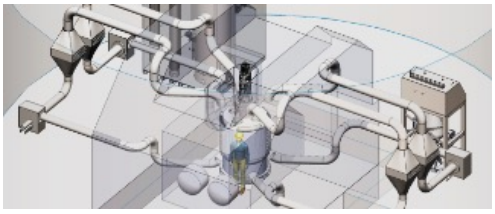
INL's industry engagement initiatives include strategic partnerships, technology transfer, and commercialization to advance its mission and support U.S. competitiveness through RD&D. INL accelerates commercialization and demonstration of existing technologies and the transition of new technologies into the private sector. There, they can be deployed to provide innovative solutions to significant societal challenges such as climate change, and to drive economic growth, including job creation. Technology transitions, commercialization, and partnerships are the final step in the chain of RD&D when INL's basic and applied research provides public benefit.

***100+** active, formalized working relationships with industry*

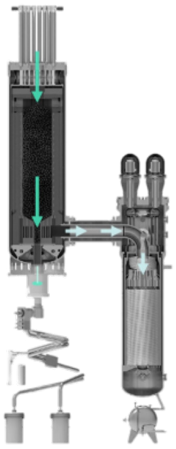
***50%** of INL's intellectual property is licensed*

***400+** active licenses*

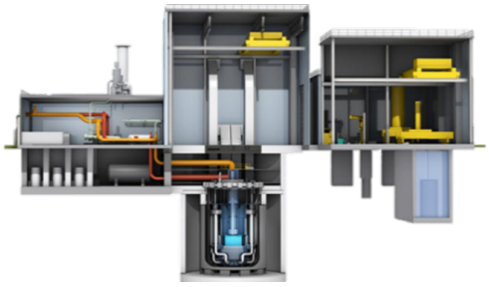
INL is a partner in all DOE Advanced Reactor Demonstration Program projects



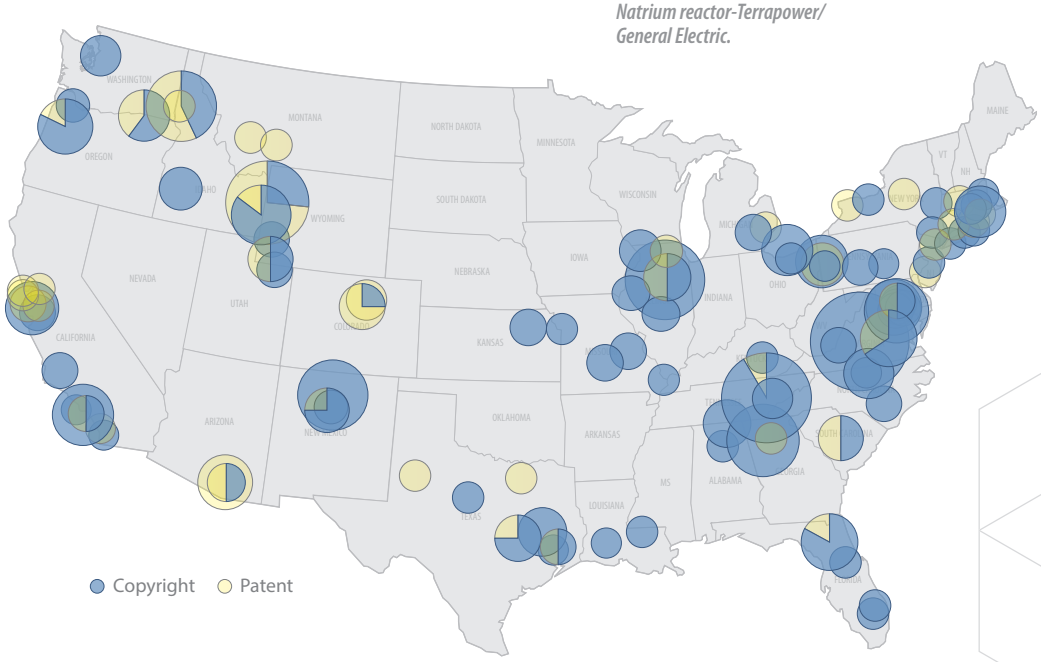
Molten Chloride Reactor Experiment- Southern Company/TerraPower.



Natrium reactor-Terrapower/ General Electric.



Reactor demonstration - X-energy's Xe-100.



INL's technology transfer impacts extend far beyond Idaho with licensed technologies across the nation.

UNIVERSITY PARTNERSHIPS

Building a Talent Pipeline and Advancing Innovation

INL builds strong relationships with colleges, universities, and other educational institutions locally, nationally, and internationally to build its talent pipeline while advancing RD&D aligned with its vision and mission.

INL has an industry-leading internship program employing 469 undergraduate and graduate students across the lab.

INL is committed to inclusive recruiting practices to accelerate the lab's access to underrepresented talent. Locally, INL engages with the Shoshone-Bannock Tribes to promote internship opportunities. Nationally, INL works to build relationships and grow collaborations with historically Black colleges and universities and minority serving institutions including efforts to co-write more research proposals, identify joint appointments, and increase outreach to undergraduate and graduate students to attract interns and postdoctoral researchers.

INL's National University Consortium includes five strategically aligned nuclear engineering departments at Massachusetts Institute of Technology, the Ohio State University, Oregon State University, North Carolina State University, and the University of New Mexico. The consortium shares capabilities to engage in collaborative research to advance DOE missions, grow technology leadership, and stimulate innovation and technical excellence. The Center for Advanced Energy Studies is a research, education, and innovation consortium that harnesses the power of collaboration to bring together INL and the three public research universities in Idaho, University of Idaho, Idaho State University, and Boise State University, to conduct cutting-edge research and educate the state's next generation of scientists and engineers.

INL National University CONSORTIUM

CAES Center for Advanced Energy Studies

Developing an interdisciplinary degree completion program in data science with Cheyney University.

INL continued its internship program and maintained the size of its intern cohort at pre-pandemic levels, despite COVID-19. Luis Nunex (left), a Ph.D. candidate at Northern Illinois University, and Christina Veney (right), studying at the Colorado School of Mines, were two of the Summer 2020 intern cohort.

67 Postdoctoral Researchers from **48** Universities

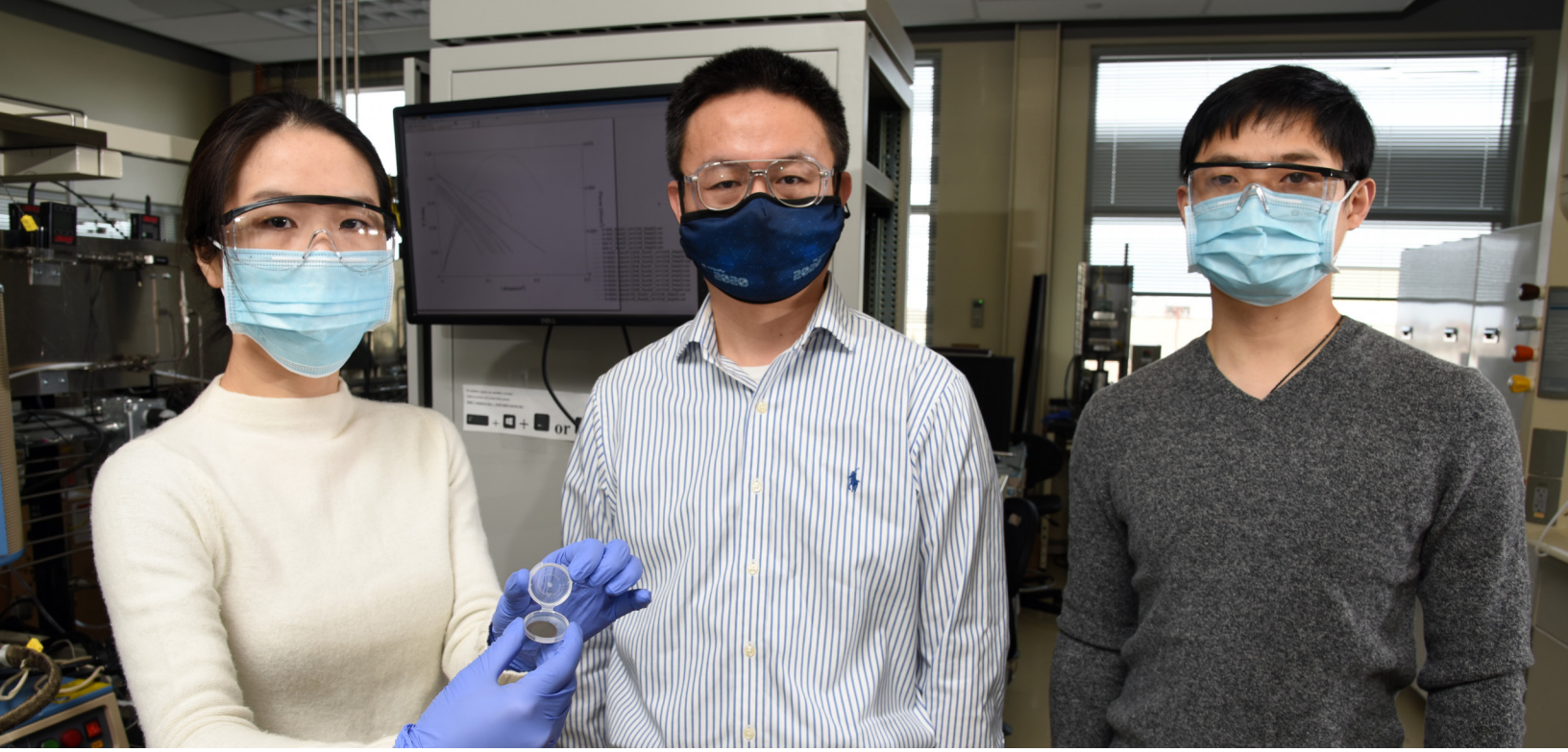
18 Faculty (teaming teachers and faculty researchers) from **14** Universities

364 Employee Education Activities from **44** Universities

29 Graduate Fellows from **16** Universities

469 Interns from **114** Universities

38 Joint Appointments from **15** Universities



INL is increasing high-impact publications, like the Nature Catalysis paper showcasing INL's capability in high temperature CO_2 conversion. Three of the paper's authors, Meng Li, Dong Ding, and Bin Hua are shown here in the Electrochemical Processing Lab.

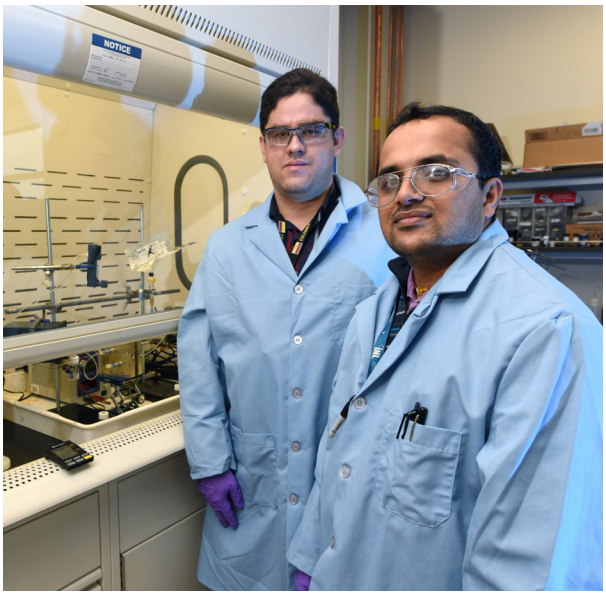
SCIENTIFIC & TECHNICAL EXCELLENCE

Leading Through Innovation and Impact

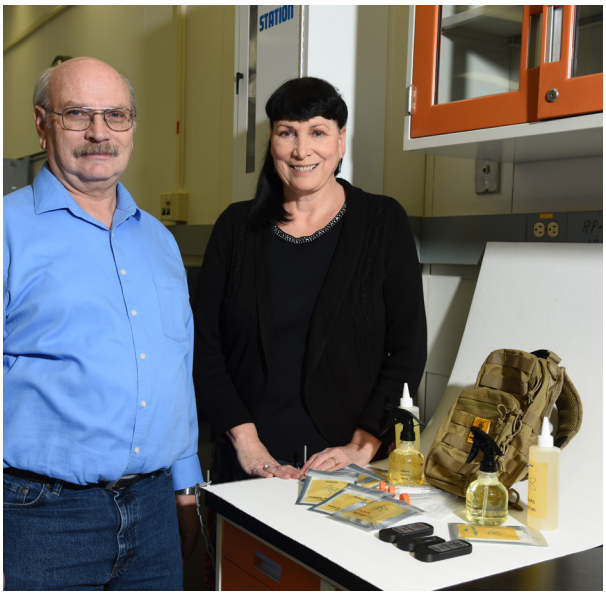
World-class researchers leverage INL's cutting-edge facilities to conduct transformative, high-impact research to change the world's energy future. INL's passionate, talented, and dedicated staff ensure that INL is at the forefront of resolving the world's most pressing energy and security challenges.

Ashly Finan, director of the National Reactor Innovation Center (left), and Christine King, director of the Gateway for Accelerated Innovation in Nuclear (right), head two INL-led DOE programs accelerating advanced reactor development and demonstration.

INL is constantly investing in the growth and improvement of its world-class research facilities, one example being the Irradiated Materials Characterization Laboratory.



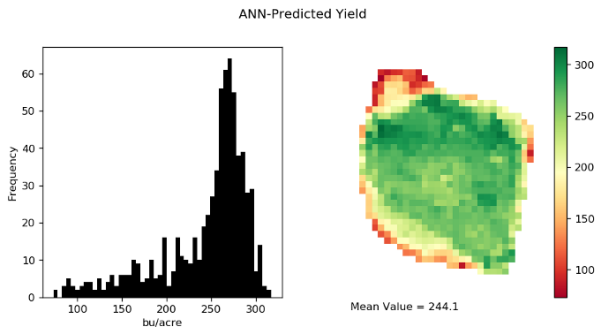
Carbon CURE researchers include Luis Diaz Aldana and Birendra Adhikari (Ningshengjie Gao, Tedd Lister, Aaron Wilson, and Eric Dufek not pictured).



The CoDeAc team included Rick Demmer and Cathy Riddle.

Won Three R&D 100 Awards in FY20

INL won three R&D 100 awards in FY20: Carbon Capture & Utilization through Reduction Electrolysis (Carbon CURE), a technology advancing economical carbon capture; Colorimetric Detection of Actinides (CoDeAc), which helps first responders quickly detect actinides at a disaster or accident scene; and Crop Artificial Intelligence Quotient (Crop AIQ) that provides agricultural performance assessments that allow land managers to make more informed decisions about how they grow plants for food, feed, fiber and fuel.



Mike Griffel, Damon Hartley, and M. Ross Kunz developed Crop AIQ to produce yield maps.

INL is committed to enhancing its research culture and is working to promote a vibrant research community through seminars, professional development, and funding opportunities.

Ted Wood, a software analyst with INL's Risk Assessment & Management Services Department, was recognized by the American Nuclear Society for his contributions to reactor safety and risk assessment.

INL's actions to ensure continuity of operations in the face of the COVID-19 pandemic included health and temperature checks, testing, and vaccinations.

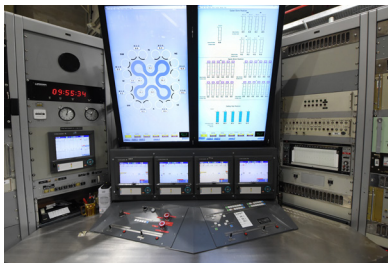
OPERATIONAL EXCELLENCE

Achieving a Culture of Safety while Advancing Mission Goals

World-leading research and engineering capabilities and exceptional infrastructure coupled with its physical geography make INL a unique location for energy and national security innovation. Reliable, safe operations and stewardship of extensive world-class RD&D infrastructure and facilities is essential to achieving INL's mission. INL facilities accommodate thousands of people daily, including employees, facility users, subcontractors, and others. Sitewide utilities and supporting infrastructure, consisting primarily of roads, railroads, and power-distribution and communication systems, are maintained and operated to serve and connect campuses and facilities. In FY20, INL continued to balance the safety requirements surrounding the COVID-19 pandemic with continuity of operations.

As INL's operations grow and evolve, the lab engages with local constituents to address the needs and concerns of community stakeholders. Because it is located on tribal ancestral land, INL works closely with DOE and the Shoshone-Bannock Tribes to assure tribal equities are strongly considered when addressing cultural resources and land use.

INL continues to expand its world-class facilities, and FY20 construction begin for the Materials and Fuels Complex Sample Preparation Laboratory.



ATR's control console was replaced in FY20, improving reliability in support of reactor operations.

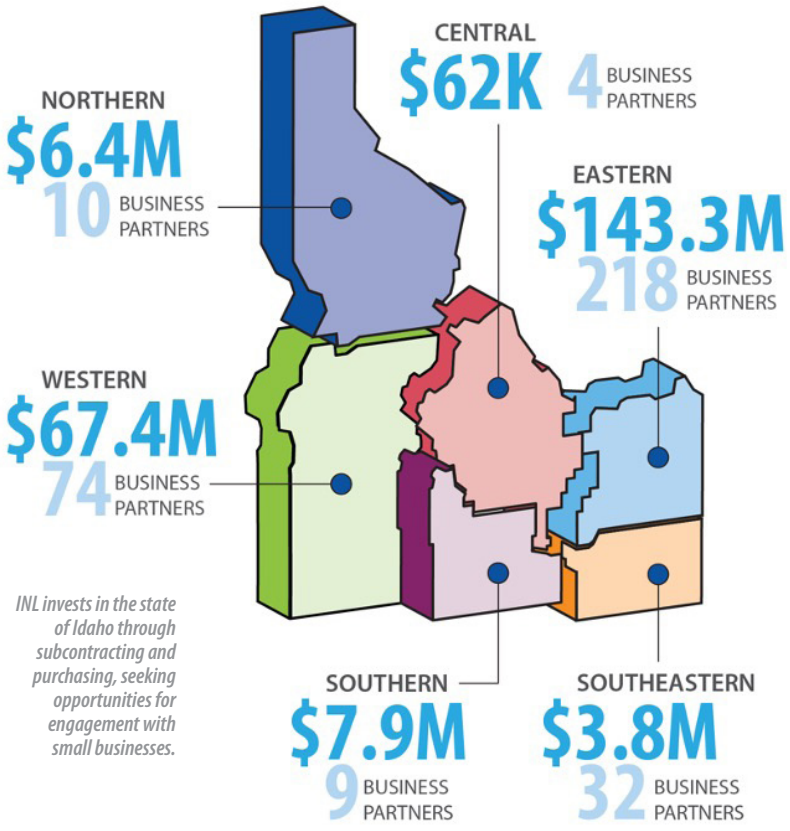
COMMUNITY EXCELLENCE

INL is Improving Quality of Life in Our Community and Region

INL is a leading employer and an economic engine for southeast Idaho, generating $2.88 billion per year in economic activity, and spending $229 million with Idaho-based companies. BEA actively invests in the community, donating $566,314 to charities in FY20 and elevating K-12 science, technology, engineering, and mathematics (STEM) education in southeast Idaho. INL provides leadership in education and helps develop a future STEM workforce through its K-12 STEM in the Lab initiative. As part of a robust statewide STEM education ecosystem, INL builds a strong STEM foundation by creating high-quality learning opportunities for all students, integrating best practices and empowering INL employees to engage as mentors and ambassadors in STEM education and work-based learning. To increase diversity, equity, and inclusion in STEM, INL targets historically underrepresented populations in STEM fields. Over 46% of INL K-12 education programs and initiatives specifically target underrepresented student populations including rural and remote, economically disadvantaged, female, and racial/ethnic minorities. To address education and workforce inequities with the Shoshone-Bannock Tribes, INL works closely with tribal leaders on STEM education programs including the Pre-Freshman Engineering Program, STEM labs, and creating career technical education pathways leading to job opportunities for tribal students.

In June 2021, INL signed a memorandum of understanding with the Shoshone-Bannock School District, leveraging the capabilities of each institution to form a demonstration project for career technical education, STEM pathways, and job placement of tribal students.

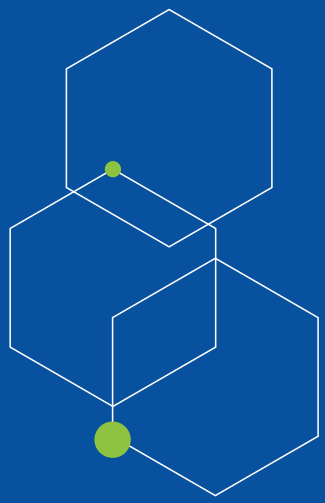
In March 2021, INL led a team and worked with Idaho Falls Power, the municipal utility serving Idaho Falls, to demonstrate the ability to blackstart five run-of-river hydropower plants and serve critical loads (like hospitals, fire stations, emergency shelters) when the transmission system is experiencing an outage.



INL invests in the state of Idaho through subcontracting and purchasing, seeking opportunities for engagement with small businesses.

***In FY20,** INL's **138+ STEM events** reached **17,751 students** and **817 teachers** and principals.*

***50%** of INL education programs and initiatives specifically **target underrepresented student populations**.*



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