Pacific Northwest
NATIONAL LABORATORY

60 YEARS of SCIENTIFIC BRILLIANCE @PNNL

LABORATORY AGENDA

June 2025

U.S. DEPARTMENT of ENERGY

BATTELLE

Dear Colleagues:

As we proudly mark Pacific Northwest National Laboratory's 60th Anniversary and look to the future, we are pleased to share our 2025 Lab Agenda. This agenda highlights our ongoing commitment to the science and technology advancement, campus transformation, core capabilities stewardship, and operational excellence that are integral to our work on behalf of our many sponsors and the nation.

Over the past year, PNNL extended its track record of delivering outstanding results with uncompromising standards for quality and objectivity. The six complementary laboratory objectives, which you will read about in this document, inspire us to achieve long-term mission outcomes in scientific discovery, energy resiliency, and national security. The continuing execution of a robust campus strategy enables our important work and empowers the thousands of professionals who perform it.

The theme of our 60th Anniversary is "Discovery and Impact: Yesterday, Today, and Tomorrow." PNNL's reputation for scientific discovery and technological innovation has grown steadily and significantly over our 60-year history as a national laboratory and continues today. We are recruiting top talent to deliver on sponsor priorities and address enduring and evolving national needs. Our scientists are advancing AI to speed scientific discovery. They are enhancing energy resilience, developing new energy storage solutions, and helping the nation meet its need for affordable and reliable electricity. And they are strengthening our national security through efforts in cybersecurity, nuclear security, and threat detection.

Our exceptional team at PNNL is poised for continued success and we are proud to present the 2025 Lab Agenda as an overview and guide for our path forward.

Best regards,

Steven F. Ashby

Steven F. Ashby
Laboratory Director

Julie K. Turner

Julie K. Turner
Pacific Northwest Site Office Manager

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT of ENERGY

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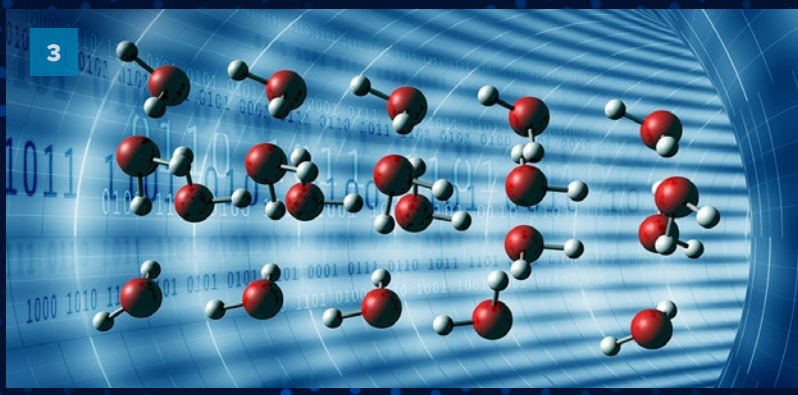
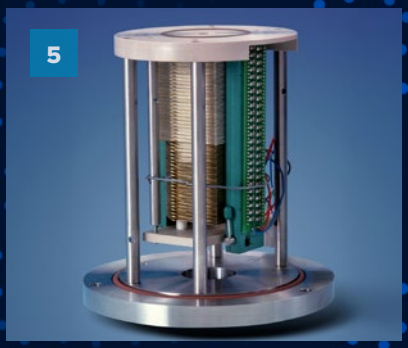
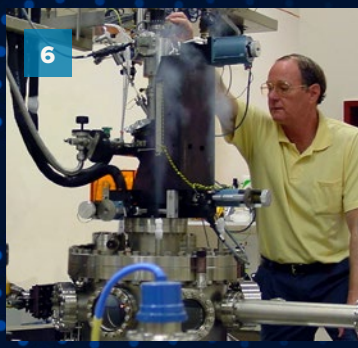
60 Years of Scientific Discovery...

Since its inception in 1965, Pacific Northwest National Laboratory (PNNL) has delivered an impressive legacy of scientific breakthroughs that have advanced the fundamental understanding of the world we live in and enabled transformative solutions for some of the nation's most pressing challenges. PNNL has harnessed multidisciplinary expertise to address critical issues in fields such as chemistry, physics, biology, and computational

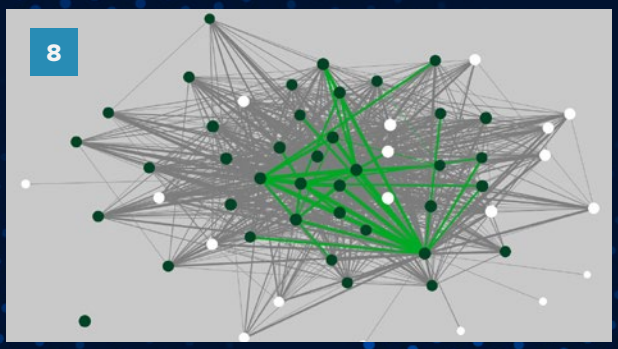


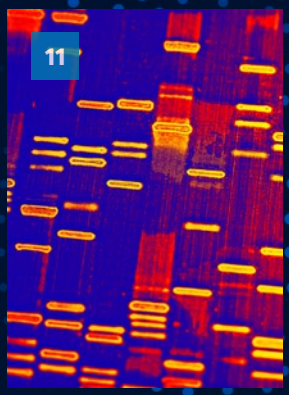




1. **Foundations of Holography.** Laboratory researchers discovered the basic inventions that form the foundation of holography, the process that captures and reconstructs three-dimensional images using light interference.
2. **Subsurface Imaging.** PNNL has been at the forefront of developing advanced subsurface imaging technologies, which are critical for environmental monitoring, oil and gas exploration, and groundwater management.
3. **Unlocking Chemistry.** The NWChem high-performance computational software model was created at PNNL. This software is one of the most used molecular science software programs for massively parallel computing in the world. It went open source in 2010.
4. **The Science of Energy Storage.** PNNL leads DOE's Batt500 program, a collaborative effort among various national laboratories, universities, and industry partners to develop advanced battery technologies with significantly better energy density and performance.
5. **Improved Mass Spectrometry.** PNNL's Electrodynamic Ion Funnel and subsequent innovations have significantly improved the sensitivity of mass spectrometry and other tools used for biological, environmental, medical, and other research.
6. **Composite Materials Synthesis.** PNNL researchers developed a means to deposit metal atoms on very thin oxide layers, making entire computer memories immediately available for use. This technique also may help fabricate less expensive catalysts, better nanotechnology devices, and improved ceramic or metal seals.
7. **Exquisite Aerosol Detection.** PNNL has developed the science underpinning sophisticated real-time aerosol detection systems that can monitor air quality and detect hazardous biological, chemical, and

and data sciences. The Laboratory's pioneering contributions are as varied as the ability to reconstruct three-dimensional structures from light interference, extract insight from massive volumes of data, develop novel catalysts and materials for energy storage and better jet fuel, extend insights into human health and disease, create metals of exquisite purity, and understand the interaction of Earth systems at all scales. As a leader in scientific discovery focused on national needs, PNNL continues to push the boundaries of knowledge, underpinning innovations that strengthen the nation's competitiveness in science and technology. See below for just a few of our contributions.





radiological agents. One application enables the detection of narcotics and explosives down to the parts-per-quadrillion in ambient air, works in seconds, and unlike canine teams, never tires or gets distracted. Another application led staff at the Lab to be the first to detect and confirm the presence of xenon-133, which had drifted almost 5,000 miles and signaled the failure of the Fukushima power plants.

8. **Extracting Information from Large Volumes of Data.** PNNL scientists developed algorithms for natural language processing that allow users to visualize patterns and relationships in extremely large volumes of data. These discoveries have been used to identify threats and trends from intelligence data, assist grid operators in managing the electric grid, identify weakness in aviation safety, and advance the speed of scientific discovery through the synthesis of experimental results and information from numerous publications.

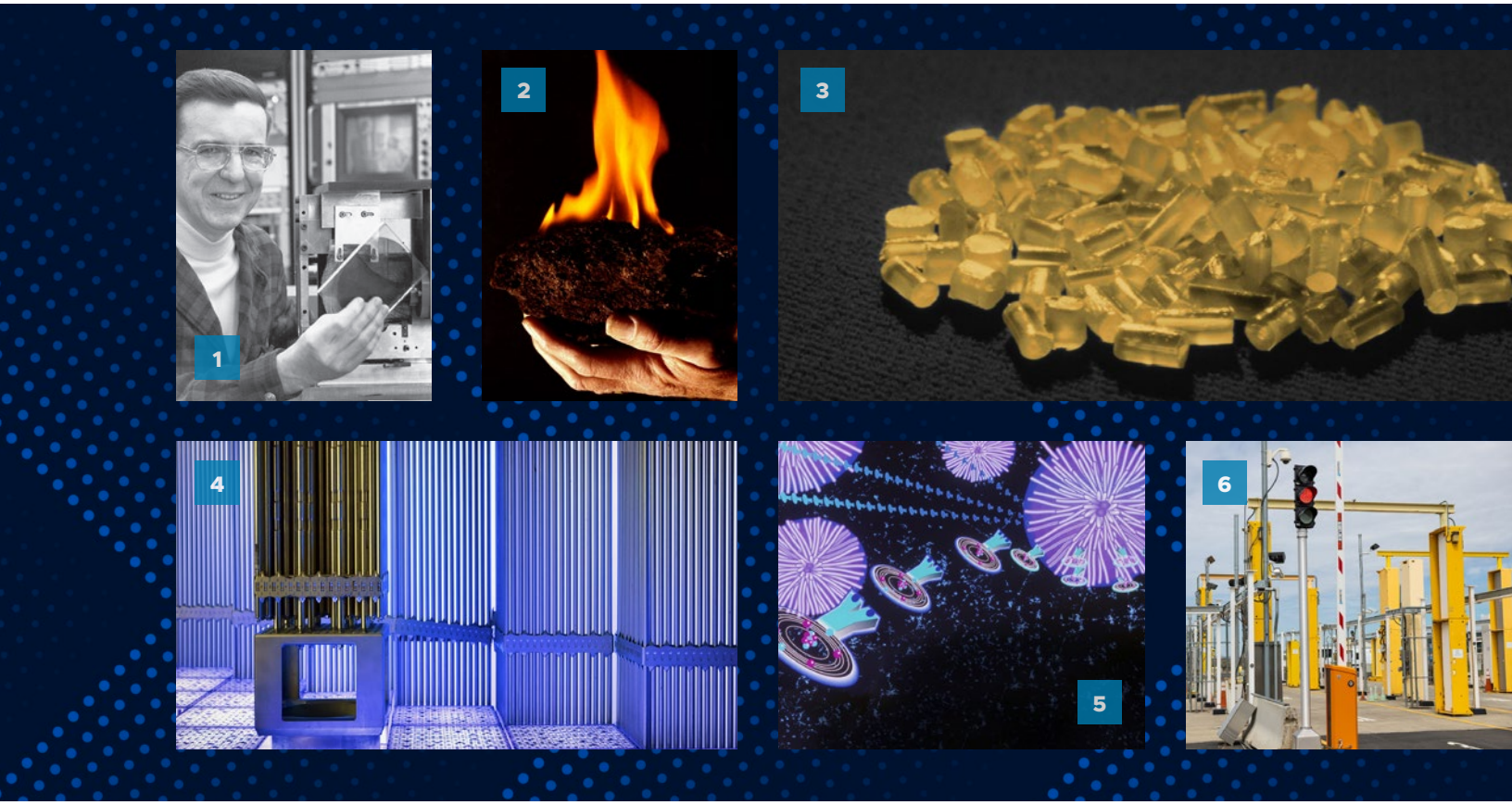
9. **Better, Faster Catalysts.** PNNL has discovered novel catalysts that accelerate our ability to turn waste plastic into new materials and fuels while using a smaller amount of precious metals than other catalysts. This discovery may ultimately enable the "upcycling" of plastics into more valuable products.

10. **Multi-scale Materials Synthesis.** PNNL scientists developed the only integrated, single-step process for materials fabrication that generates nano- to macro-sized materials with identical chemistry characteristics for use in materials science research.

11. **Finding Malware DNA.** Borrowing from biology, PNNL scientists developed the means to convert software code into DNA-like structures and then identify any code that contains similarities with known malware. This one-of-a-kind detection approach can identify never-before-seen malware and provides a new level of protection against large-scale, debilitating cyberattacks.

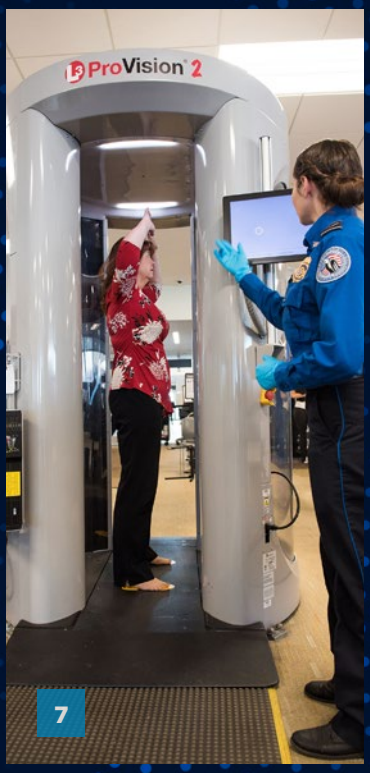
...and 60 Years of Technological Impact

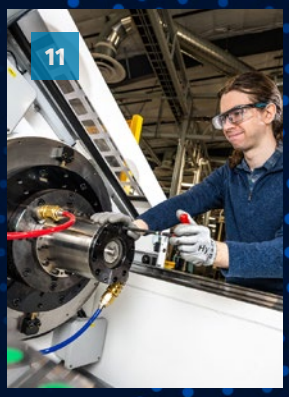
Over the last six decades, PNNL has been at the forefront of groundbreaking research and development, driving technological advancements that have profoundly impacted the United States across various sectors. PNNL has leveraged its expertise in science and engineering to address important challenges in national security, energy resilience, and scientific discovery. Its innovations have transformed the operation of the North American electric grid, revolutionized the ability to improve nuclear security and nonproliferation at our borders, secured energy systems and other infrastructure from cyber threats,



1. **Optical Digital Recording.** This invention made it possible to store information as a track of tiny dots 70 times smaller than the diameter of a single strand of human hair. It became the basis for CDs and DVDs, which revolutionized the music and entertainment industry.
2. **Hazardous Waste Vitrification.** PNNL scientists developed a technology for incorporating high-level radioactive waste in a stable glass form suitable for permanent geologic disposal.
3. **Bio-barrier Material.** Now used nationwide, this PNNL-developed material prevents unwanted root growth and vegetation from invading septic tanks, roadways, sidewalks, and buried gas pipes.
4. **Commercial Reactor Technology.** PNNL fabricated the first tritium-producing absorber rods inserted in a commercial reactor, removing the need for the operation of special production reactors.
5. **Radiochemistry for Cancer Treatment.** Starting in the late 1990s, PNNL scientists developed a process for extracting highly pure yttrium-90 from nuclear waste for use in nuclear medicine and cancer treatments. The process was commercialized in 1999; Y-90 is now the active ingredient in cancer drugs used world-wide.
6. **Border Protection.** PNNL-developed radiation portal monitoring technology, installed at every U.S. port of entry, thwarts illicit trafficking of nuclear and radiological materials into our country.
7. **Airport Security.** PNNL's pioneering research in optical and acoustic holography in the 1960s led our researchers to determine how to use millimeter waves to penetrate clothing and scan for concealed objects—e.g., explosives in shoes—resulting in the now ubiquitous body scanners found at most airports in the United States and abroad.

stabilized hazardous wastes, and invented new research tools with unprecedented levels of sensitivity, precision, and autonomy to accelerate the process of scientific discovery itself. With its commitment to multidisciplinary collaboration and an emphasis on developing technological solutions hand-in-hand with those who will be applying them, PNNL continues to play a pivotal role in shaping a secure future for the United States amidst evolving global challenges. See below for just a few of our contributions.





8. **VOLTTRON™.** PNNL developed a distributed sensing and control platform to manage heating, ventilation, and air-conditioning systems in buildings, coordinating its actions with the grid, to optimize commercial and residential building electricity loads and reduce costs.
9. **Self-healing Cement.** PNNL developed a self-healing cement that can repair itself within 24 hours when cracked or damaged. The key is a restorative polymer component material that migrates toward cracks, re-bonds, heals fractures, and imparts flexibility, fully restoring the mechanical integrity for the lifetime of the material. Cracked cement is a persistent problem for the oil and geothermal industries, which use the material to build subsurface wells.
10. **Nuclear Explosion Detection and Analysis.** The ability to accurately detect nuclear explosions is a key component of national security and international treaty monitoring. PNNL researchers have doubled the sensitivity and speed of existing monitoring capabilities, and working with an industry partner, developed a fully automated system to continuously monitor for evidence from underground nuclear explosions.
11. **Manufacturing Novel Materials: ShAPE™.** PNNL has developed an innovative manufacturing approach for the extrusion of metal alloys and composites with homogeneous microstructures and improved performance, while also reducing energy consumption and production costs, to enable next-generation materials for a wide variety of high-tech industries.

TODAY

OUR MISSION

From its origins supporting the Cold War mission of the Hanford Site, PNNL has grown and evolved in the reach of its mission, societal impact, and reputation. Today, the Laboratory's research priorities concentrate on three mutually supporting principal missions addressing major challenges of national and global consequence:

Scientific Discovery: Building on long-standing, distinctive strengths in chemistry, Earth sciences, biology, and data science.

Energy Resiliency: Enhancing the flexibility, reliability, and security of the U.S. electric power system through innovation in energy storage technologies and grid controls.

National Security: Developing new technologies to detect weapons of mass destruction, enhance nuclear materials characterization and forensics techniques, and anticipate and respond to new security threats as they emerge.

OUR CORE CAPABILITIES

The scope of PNNL's research and development toolkit—its core capabilities—has expanded in conjunction with the growth of the Laboratory's mission scope. PNNL stewards 22 U.S. Department of Energy (DOE)-recognized core capabilities, each representing a combination of world-class science and engineering expertise, state-of-the-art equipment, and mission-focused research facilities. PNNL's core capabilities are organized into five areas: 1) Chemical and Materials Sciences, 2) Computational and Mathematical Sciences, 3) Biological and Earth Sciences, 4) Engineering, and 5) User Facilities and Advanced Instrumentation.

OUR ORGANIZATION

Endowed with a consequential mission and transformative capabilities, PNNL conducts its research by organizing its programmatic activities via four principal science and technology organizations, its research directorates: National Security, Energy and Environment, Earth and Biological Sciences, and Physical and Computational Sciences.




The following pages showcase each directorate, highlighting distinctive research areas and major impacts and accomplishments. The research directorates are the heart of PNNL's innovation, through which today's bold scientific visions become tomorrow's reality.

National Security

Protecting the American people is among our nation's highest responsibilities. As adversaries gain access to sophisticated technologies and materials, the threats to our nation grow more dynamic, complex, and varied—from cyber and nuclear to chemical and biological weapons of mass destruction and other forms of terrorism.

Faced with these realities and their impact on national security, PNNL develops science-based solutions that keep America safe. We drive innovation and critical capabilities in nuclear security, nuclear stockpile science, threat analysis, cybersecurity, computational and data science, and other areas of expertise to secure our nation's critical infrastructure, combat global terrorism, and detect concealed threats and explosives.

PNNL offers distinguishing expertise and capabilities in:

Nuclear, Chemical, and Biological Technologies: Works to counter emerging national security threats. We are focused on discovering signatures and understanding threats by creating materials, methods, and technologies to detect and analyze them to deliver the solutions necessary for addressing complex mission challenges, from explosives and biological threat detection to chemical and nuclear forensics to special nuclear materials.

Physical Detection Systems and Deployment: Discovers, develops, and deploys physical detection systems. We steward deep subject matter expertise in physics, materials science, engineering, and project execution, integrating these disciplines to transition technology into operational environments domestically and in more than 100 countries around the globe.

Emerging Threats and Technologies: Stewards cybersecurity, analysis, and security cooperation capabilities to provide insight into opportunities and threats brought about by emerging and disruptive technologies. Researchers harness deep mission-specific expertise to conduct analyses of intelligence information, cybersecurity data, laws, and regulations on behalf of the national security community.

AI and Data Analytics: Advances data science through foundational and applied research. Our team of software engineers is integrating AI solutions into critical operational missions and redefining the frontier of advanced data analytics, driving innovation and shaping the future of technology.

Nuclear Security and Forensics

Since the end of the Cold War, PNNL has played a critical role in advancing nuclear security and preventing the spread of nuclear weapons. With decades of experience, PNNL develops and deploys cutting-edge technologies to detect, monitor, and secure nuclear and radiological materials across the globe. The Lab is a national leader in radiation detection systems, creating tools that are used at border crossings, airports, and seaports to identify illicit nuclear material in transit. PNNL also specializes in nuclear forensics—analyzing trace evidence to determine the origin and history of nuclear materials—and supports efforts to verify compliance with nuclear treaties and help disrupt the trafficking of nuclear materials. Our scientists work closely with DOE, the Department of Homeland Security, and other agencies to provide technical expertise and operational support. Through these efforts, PNNL helps prevent nuclear terrorism, counters the threat of rogue states acquiring nuclear weapons, and reinforces global norms against the spread of nuclear arms.

Energy and Environment

Ensuring that all Americans will have access to enough reliable and affordable energy to meet the growing demand is one of our nation's grand challenges—PNNL is at the forefront of delivering the science and technologies to meet that need. Our researchers focus on modernizing the nation's power delivery and grid infrastructure; advancing technologies that improve the reliability, affordability, security, and resiliency of the U.S. energy system; and resolving complex issues in nuclear science and environmental management.

PNNL offers distinguishing expertise and capabilities in:

Electricity Infrastructure and Buildings: Leverages capabilities in grid modeling, contingency analysis, and high-performance computing, equipping grid operators and planners with powerful tools to help modernize U.S. energy systems and infrastructure and improve their resilience. Our expertise in building technology design and performance evaluation supports discovery of affordable solutions for more efficient building operations that reduce ongoing energy costs.

Energy Processes and Materials: Leverages our science and engineering capabilities in battery technologies, smart advanced manufacturing approaches, biomass conversions, applied catalysis, and advanced separations to deliver scalable solutions that address DOE mission goals for affordable, reliable energy for the nation.

Nuclear Sciences: Encompasses PNNL capabilities and expertise in nuclear science and engineering, along with environmental management. We help to close persistent knowledge gaps regarding nuclear materials behavior and develop novel radiochemical processes to advance nuclear energy, resolve legacy waste challenges, and support national security goals.

Coastal Sciences: Leverages PNNL's research facilities on Sequim Bay in Washington state to support capabilities in coastal monitoring and forecasting, marine energy technologies, and hazard assessment, providing integrative solutions to support economic growth and national security. By advancing our understanding of complex coastal systems and their impact on energy resilience, we equip DOE decision-makers with tools to address a broad array of challenges, ensuring the vitality of our coastal infrastructure and assets for future generations.

Earth System Sciences: Focuses on understanding, assessing, and mitigating operational risks at the interface of human and natural environments to support decision-making, with the goal of better predicting the impacts of natural hazards on energy system resilience and national security. We steward a breadth of capabilities—including Earth and energy systems, subsurface science, infrastructure analysis, engineering, and decision science and analysis—to develop tools and solutions to address these complex challenges.

Electric Grid Modernization

The U.S. grid is often described as one of the greatest engineering achievements of the 20th century; however, it will take innovative solutions to prepare the grid to meet our country's increasing energy demand. A resilient power grid is vital to the national security, economic security, and energy reliability our country needs. Assuring this resilience requires identifying and mitigating physical threats to infrastructure and cyber threats across both information technology and operational technology systems. It will also require providing grid operators with the situational awareness and control capabilities to manage a variable energy generation mix combined with an increasing number of large electric loads.

PNNL has the scientific expertise and technical resources to take on the toughest grid modernization challenges. PNNL research advances a power grid that:

- Enables real-time predictive operation to improve reliability and efficiency.
- Incorporates advanced controls that engage new devices and enable new services at scale while ensuring resilience.
- Leverages new approaches and technologies—such as energy storage, microgrids, transactive energy, machine learning, and AI—to provide flexibility in support of an array of energy futures.

Earth and Biological Sciences

Biological and Earth system processes are incredibly complex, spanning a wide range of spatial scales. Understanding these systems is essential for meeting national priorities such as ensuring energy dominance and protecting critical assets. PNNL scientists leverage our expertise in microbial systems, biotechnology, and advanced computation to enable predictive understanding and design of valuable molecular functions. Similarly, we are developing dynamic digital testbeds that bring together diverse data sources, Earth and energy systems models, and AI to understand and predict human–Earth system interactions.

PNNL offers distinguishing expertise and capabilities in:

Biological Sciences: Encompasses topics relevant to the bioeconomy, bioenergy, human health, and national security. Researchers use advanced instrumentation, unique data sources with integrated computational approaches, and deep domain expertise to explore and predict molecular- to systems-scale processes. Strategic efforts focus on advancing molecular measurement capabilities, determining the functions of biological molecules, identifying system control points, and developing domain-aware AI to accelerate discovery and hypothesis-driven research.

Environmental Molecular Sciences: Deciphers molecular-level interactions driving biological and environmental processes across temporal and spatial scales, thus enabling a predictive understanding of these systems. PNNL also manages the Environmental Molecular Sciences Laboratory (EMSL), a DOE user facility designed to accelerate the research of scientists world-wide through the provision of world-class expertise, instrumentation, and computational resources.

Joint Global Change Research Institute: Advances the fundamental understanding of human and Earth systems related to global change, energy, and environment. This research, completed in partnership with the University of Maryland, supports public decision-making, but is not policy prescriptive.

Atmospheric and Earth System Science: Advances predictive knowledge of integrated Earth and energy systems by combining world-wide field observations, laboratory research in aerosols and clouds, and AI-assisted regional and Earth system modeling to support a resilient U.S. energy system. In addition, we comanage the Atmospheric Radiation Measurement (ARM) User Facility, which provides 30-plus years of continuous atmospheric measurements, including data sets from all seven continents and five oceans, to advance the understanding of the Earth's atmosphere.

Transforming Bioenergy and Biomanufacturing for a Thriving Bioeconomy

The bioeconomy holds immense potential for 21st-century economic growth, with estimates projecting an annual global value of 4 to 30 trillion dollars by 2050. PNNL is at the forefront of this growth, advancing foundational and translational sciences to boost U.S. manufacturing through bio-based innovation.

PNNL is integrating advanced molecular profiling with AI-driven autonomous research to predict, design, and optimize biological systems central to industrial production processes for applications such as bioenergy, biomanufacturing, and critical materials extraction.

To this end, PNNL is pioneering work in the "science of scale-up," which is crucial for transitioning biological manufacturing from experimental laboratory scales to industrial-scale production. This research enables us to predict factors expected to change during scale-up, improving our design of biomanufacturing processes.

PNNL's research advances efficient, biology-based production and processing systems, driving the bio-revolution and positioning biotechnology as a foundation for advancements in energy, manufacturing, and critical minerals extraction. Our efforts secure the dominant role of the United States in the bioeconomy, both now and in the future.

Physical and Computational Sciences

Physical and computational sciences play a pivotal role in enhancing U.S. innovation and scientific leadership, which are foundational to the economic productivity, national security, and energy reliability of our country. PNNL's research in these fields explores experimental, computational, and theoretical chemistry; materials science; quantum computing; isotope research and production; advanced computing; AI; and autonomous science. Our long-standing strengths and capabilities in chemistry and catalysis have earned PNNL its reputation as "DOE's chemistry laboratory." Our research also emphasizes the application of these disciplines to PNNL's other signature research domains, including microbial biology, nuclear detection and forensics, electric grid control and resiliency, and cybersecurity research. PNNL tackles some of the most significant physical and computational science challenges of our era. We are leading the design and synthesis of new materials for batteries and nuclear reactors, meeting crucial national supply chain demands through the purification of isotopes, and addressing currently unsolvable problems with advanced computing architectures, such as those developed for quantum computers. A particular area of emphasis for us is in developing the autonomous experimentation capabilities that will accelerate the process of scientific discovery across all our research domains.

PNNL offers distinguishing expertise and capabilities in:

Physical Sciences: Encompasses basic and applied chemistry in catalysis, materials science, separations, analytical chemistry, heavy element chemistry, geosciences, and chemical physics. Our research strives to refine our molecular-level understanding of complex, multiphase systems and phenomena. We discover and apply new knowledge to address major national priorities and needs through the development of new energy storage technologies, the creation of high-value fuels and materials from abundant waste, and the generation of new separation strategies for critical materials.

Advanced Computing, Mathematics, and Data Science: Drives innovation in computing and AI to accelerate discovery across scientific domains. We leverage our deep expertise in applied mathematics, machine intelligence, high-performance computing, and data and computational engineering, combined with end-to-end codesign to improve the energy-efficiency of computing systems. Our work addresses the enormous and rapidly growing energy demands of AI systems while advancing the convergence of next-generation AI and quantum algorithms. We focus on the development of future heterogeneous computing systems and advanced algorithms designed to analyze, model, and control the behavior of complex systems in science, energy, and national security.

Assuring the Domestic Supply of Isotopes

PNNL has a long tradition in radioisotopes research, built in part on PNNL's radiochemical processing expertise and its specialized facilities, such as the Radiochemical Processing Laboratory, for handling high-activity materials. Notably, PNNL produced and shipped initial research quantities of actinium-225 (^{225}Ac) and its decay product, radium-226 (^{226}Ra), to U.S. medical researchers, thus supporting the development and availability of targeted alpha therapy isotopes, which are used in precision medicine for treating cancer. PNNL researchers also designed and patented the first automated, computer-controlled ^{225}Ac/bismuth-213 (^{213}Bi) generator using anion-exchange technology, assuring a reliable source of ^{213}Bi for cancer treatment.

Today, PNNL continues to lead projects in isotope production and separations involving these alpha-emitters and is a leader in research and development of separations of other alpha-emitting isotopes, including lead-212 from thorium sources. These projects underline PNNL's role in generating new ^{225}Ac supplies and safely managing ^{226}Ra feedstock for consistent medical isotope production. In addition, PNNL is developing methods to recover and recycle legacy radium sources and supporting federal initiatives to ensure a robust U.S. domestic supply chain to reduce reliance on foreign or limited stockpiles.

Our People

Great research does not start with laboratories, equipment, and facilities. It starts with great ideas—and great people.

At PNNL, we cultivate scientists, engineers, and support professionals of diverse backgrounds, perspectives, and talents. They have in common a shared excitement about the possibilities of science and technology, and a commitment to creative approaches to complex problems. By prioritizing well-being, fostering a collaborative culture, cultivating resilient leadership, and enabling career growth, PNNL is a national leader in workforce development and innovation. Our strategy has four parts:

- We emphasize the **Whole PNNLer**. We provide enhanced mental health resources, preventive health programs, and work-life balance initiatives, in addition to competitive and equitable compensation structures, modernized recognition programs, and real-time performance feedback mechanisms.
- We are dedicated to **WE Culture**. By embedding a sense of WE into all aspects of PNNL culture through workshops, leadership development, staff engagement, and psychological and physical safety programs, we reinforce our foundation of excellence through a commitment to shared purpose.
- We are focused on the growth of our **next leaders**. We are expanding programs to give our staff tools to enhance their resilience, adaptability, and strategic decision-making, and are implementing a robust succession strategy.
- We are committed to providing clear **learning and career pathways** for all staff. We are expanding mentorship opportunities and access to our dedicated learning academy, offering opportunities through our many university partnerships, and have established an internal talent marketplace to help align employee aspirations with Lab opportunities.

Our Partnerships

The big research questions are bigger than we are, bigger than any individual institution. These questions inspire our collaboration with other DOE national laboratories and with leading university and industry partners around the world and spur us to consider problems from new angles and perspectives. Partners complement one another's strengths and venture together to places they could not go alone.

ACADEMIA

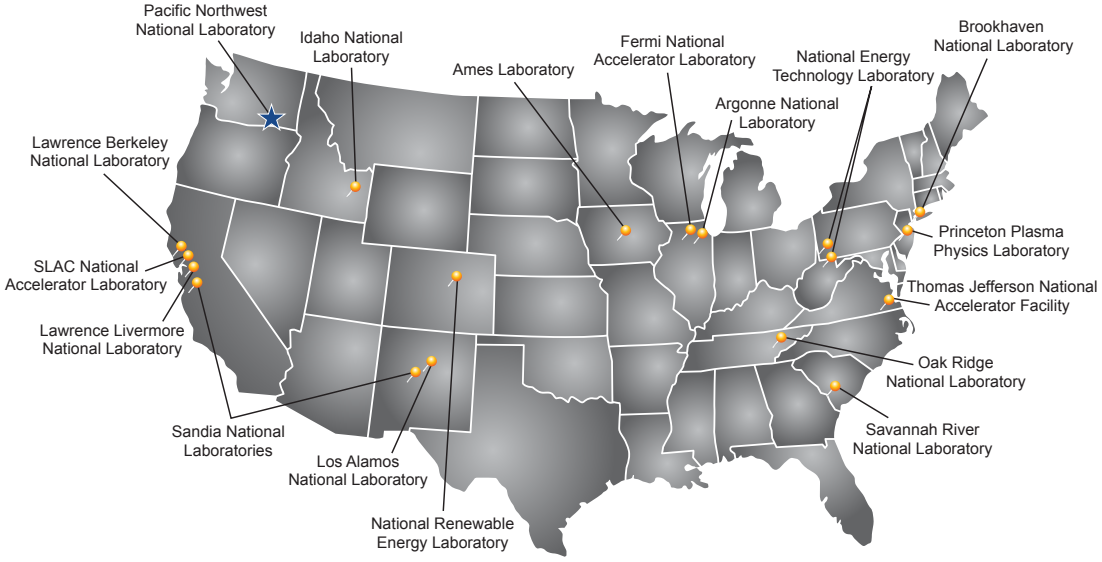
Partnerships with universities are critical to our success. Joint research institutes, dual faculty appointments, internships, and distinguished graduate research programs all offer PNNL scientists and academic partners opportunities to share unique facilities, expand access to new ideas and great minds, and cultivate the next generation of scientific and technical talent. PNNL hosts joint institutes with Washington State University, Oregon Health & Science University, University of Maryland, University of Washington, and Georgia Institute of Technology.

INDUSTRY

Our work with industry partners allows us to move technology out of the laboratory and into the world to address real needs and problems. Making our intellectual property available to industry—through licensing, collaborative research and development, or other mechanisms—is part of our mission as a national laboratory.

OTHER DOE NATIONAL LABORATORIES

PNNL is one of 17 DOE national laboratories, often called the crown jewels of the U.S. scientific enterprise, that collaborate to bring their individual strengths and capabilities to bear to ensure the nation's continued access to the best scientific ideas and innovative solutions to national needs.



Our Contributions to STEM

PNNL fosters strong foundations in science, technology, engineering, and mathematics (STEM) literacy and helps prepare a highly skilled future STEM workforce as a means for ensuring ongoing U.S. competitiveness and scientific leadership. To this end, we develop strategic partnerships, engage students and educators, and build STEM capabilities that align with our mission and DOE's scientific priorities.

We support the communities in which we live and work by collaborating with local K-12 and higher education institutions. For example, through the Yakima Valley/Tri-Cities Math, Engineering, Science Achievement (MESA) College Prep program, we provide middle and high school students from Yakima Valley and Mid-Columbia school districts with enriching STEM readiness and career-connected opportunities. These activities inspire and prepare them for post-secondary STEM education careers.

As another example, the PNNL Student STEM Ambassadors program engages students, educators, and community members through in-person and virtual classroom visits, outreach activities, and community events. Our STEM Ambassadors host STEM career pathway sessions and meet with undergraduate and graduate students in and around their Pacific Northwest home institutions to promote DOE internship opportunities. In FY 2024, PNNL hosted 1,717 interns and research associates. PNNL's STEM Education and Workforce Development programs impacted 53,115 students and over 920 educators. These activities underscore PNNL's commitment to inspire the next generation of the STEM workforce, promote educational excellence, strengthen the communities we serve, and contribute to continued U.S. scientific leadership.

Our Community

The Pacific Northwest is our home, not just our name. Eastern Washington state and the Northwest region play a big part in shaping our staff, culture, and values—and have since PNNL was founded in 1965.

PNNL participates in community life in many ways and on many levels. Last year, for example, individual staff members and Battelle-sponsored community projects accounted for 45,000 volunteer hours. We helped build local homes with Habitat for Humanity, and tutored local students in math and science.

Our partnerships with area schools promote STEM education and workforce development. We sponsor internship programs, computer science hackathons, and scholarship aid.

Battelle and PNNL are founding sponsors of Delta High School, a science and technology magnet school in the Tri-Cities. Both Battelle and PNNL partner with the Tri-Cities Chamber of Commerce and TRIDEC, an economic development company, to attract new businesses and to find new ways to provide local small businesses access to PNNL laboratory spaces.

Our community extends to the entire Pacific Northwest. Staff members at PNNL have leadership roles in the Association of Washington Business, the Washington Roundtable, the CleanTech Alliance, and other regional organizations.

TOMORROW

LABORATORY OBJECTIVES

PNNL provides the science needed to support U.S. government efforts to make Americans' lives better through access to plentiful and reliable energy, dominance in the emerging field of AI and its use, and the assured safety, security, and prosperity of our nation.

We are leaders in the science that underpins:

1. The safety, security, reliability, and resilience of our nation's electric grid.
2. The application of AI and data science to national security challenges, including nuclear forensics, border security, and the global trafficking of weapons of mass destruction.
3. The precision synthesis, in-situ characterization, and scale-up/manufacturability of materials designed for specific purposes, such as those required for current and future nuclear reactors, grid-scale batteries, or threat detection.
4. U.S. leadership in the developing bioeconomy, specifically the use of microbial communities to enhance energy diversification, manufacturing, and biosecurity and forensics.
5. The development of the next generation of catalysts and enablement of the application of quantum computing to chemistry and associated challenges.
6. The ability to understand and predict how Earth systems—air, water, and land—will impact energy systems and infrastructure, and thus mitigate negative effects to the nation's economy.

PNNL specializes in problems demanding a deep understanding of large-scale, complex systems and succeeds by applying end-to-end capabilities in characterization, modeling, prediction, synthesis, detection, and mitigation to the challenge at hand. In the six major laboratory objectives that follow, you will see our plans for the future.

Enhancing Grid Reliability and Security with Advanced Controls and Energy Storage

Our Goal: PNNL will develop and demonstrate next-generation grid controls and energy storage technologies to meet rising electricity demands while increasing the reliability and security of the U.S. electric grid.

The Challenge: The United States is projected to experience rapid electricity load growth over the next 10 years, driven by data centers, manufacturing, and the electrification of buildings and transportation. Inverter-connected resources will significantly alter energy flow control at various levels. The system's operational complexity will rise due to the increasing deployment of grid-edge devices, requiring coordination with inertia-based generation. Current grid control technology and methodologies hinder the ability to harness available resources effectively to meet increased demand, reliability, and resiliency economically.

This research leverages PNNL's access to the most extensive historical and current U.S. grid planning and operational data through the Electricity Infrastructure Operations Center (EIOC). The EIOC integrates industry-grade planning models and real-time grid sensor data with PNNL's scientific capabilities in power system engineering, mathematics, algorithm development, AI and machine learning, and data analytics.

Our Approach: PNNL will focus on two critical areas to enable an affordable, reliable, resilient, and secure U.S. electric grid:

1. Developing next-generation grid control technologies for operations at the required scale and speed.
2. Accelerating the identification and deployment of low-cost, earth-abundant energy storage materials and systems for transportation and grid applications.

Recent Accomplishments: In 2024, PNNL inaugurated the Grid Storage Launchpad, a 93,000 sq. ft. facility focused on materials development, in operando characterization, device prototyping, and 100 kW test chambers. This facility accelerates the development and testing of low-cost, grid energy storage technologies under realistic conditions.

Critical Partnerships: PNNL is committed to its longstanding relationships with public and private utilities across the country to whom it provides timely access to energy threat intelligence. Collaborations with experts such as AWS and Microsoft, to name just two, explore distributed grid control and the application of AI and machine learning in designing better materials. Support from DOE's Advanced Scientific Computing Research program is enabling PNNL to scale multiperiod grid optimization code to run on exascale computers to examine increasingly complex and stochastic planning scenarios and operational conditions.

Assured Autonomy

Our Goal: By advancing the fundamental understanding of mathematics and computing to characterize, predict, and control AI behavior, PNNL will enable autonomous science, energy, and security applications.

The Challenge: AI is transforming the process of scientific discovery, but fully realizing its potential will demand as yet unachieved levels of reproducibility, reliability, and confidence in its application. This, in turn, will necessitate new mathematical approaches to constrain undesirable system dynamics, and assured models that can be embedded in a framework that combines AI-driven hypothesis generation with automation and robotics to power autonomous experimentation and discovery.

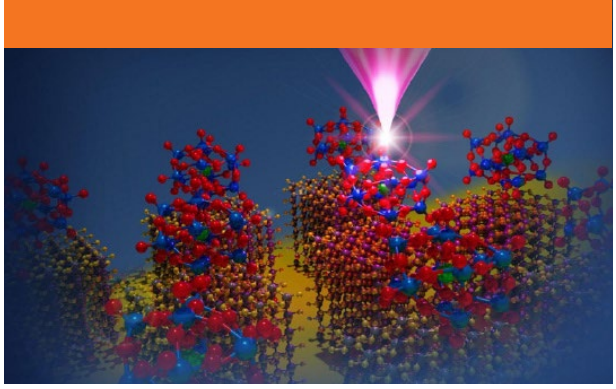
Based on its research in few-shot learning, AI assurance, and human–machine teaming, PNNL currently is a leader in developing and deploying large-scale AI systems for national security applications. PNNL has also established strengths in domain-informed machine learning in areas including catalysis, microbial biology, and the U.S. electric grid.

Our Approach: PNNL will advance the field of AI and redefine how science is conducted in the AI era through two complementary themes:

1. Establishing the mathematical and algorithmic basis for robust and reliable AI models.
2. Creating a new paradigm for autonomous agents capable of independently performing sophisticated research tasks, both logical (i.e., AI-driven reasoning) and physical (i.e., robotic laboratory operations).

Recent Accomplishments: PNNL has developed a methodology to evaluate AI models based on our fundamental research in the underlying mathematics of neural networks. This methodology has been encapsulated in software that is now used by sponsors to assess AI models. In addition, PNNL has launched new autonomous laboratories that both advance our understanding of autonomous experimentation and accelerate discovery in critical science domains.

Critical Partnerships: Leading private sector innovators are increasingly seeking partnerships with national laboratories to benefit from their scientific expertise and advance their models for discovery. PNNL is working with Microsoft, OpenAI, AWS, and Anthropic to facilitate the integration of industry insights into PNNL's missions while transitioning its scientific discoveries into commercial solutions. These efforts are leveraged to drive early-stage research in autonomous control of dynamical systems and to cultivate the future AI workforce for DOE missions.



Materials Worth Making

Our Goal: PNNL will accelerate the innovation of deployment-ready resilient materials by advancing scalable synthesis methods and predictive analytics of degradation processes, enabling technologies that deliver reliable and affordable energy to the United States.

The Challenge: Our nation's energy security and industrial leadership hinge on the development of resilient materials capable of withstanding harsh operational environments, including mechanical stress, radiation exposure, and thermal cycling. While computational methods excel at predicting materials with promising properties, we struggle to use them to identify which candidates are synthetically viable and whether predicted properties will persist after processing into application-ready forms, like thin films or cables, and during long-term device operation. The concept of "deployment-ready" materials represents a new frontier in materials science, requiring computational models to transcend mere inherent property prediction and accurately forecast both scalable synthesis processes with morphological control and emergent behaviors under diverse operational environments.

This research leverages PNNL's extensive repository of synthesis and operando characterization data from the decades of research as DOE's lead chemistry laboratory, and our historic strengths, derived in part from our national security work, in data science and the application of AI and machine learning to experimental design.

Our Approach: PNNL will pursue "resiliency by design" by establishing a computational framework that combines physics-based materials discovery with experimental data-driven emerging property predictions to accurately map structure-resiliency relationships. Our research is focused on:

1. Predicting emergent properties under complex operational environments.
2. Bridging the gap between computational discovery and manufacturable materials.

Recent Accomplishments: PNNL recently has achieved success at both ends of the synthesis scale. We have demonstrated the ability to create friction-extruded copper wires with parts-per-million graphene and exceptional electrical performance at scales relevant for application to the grid. In addition, we have used directed epitaxial growth and molecular assembly to create precision synthesis pathways that enable controlled material formation at the atomic and molecular level, relevant to advances in microelectronics.

Critical Partnerships: Our current partnership with Microsoft leverages the Azure high-performance computing platform for AI-driven materials discovery, with an emphasis on developing synthesis processes and experimentally validating predicted properties. Other collaborations with industry and academia are expanding our operando testing capabilities, specifically for atomistic visualization of metal alloy degradation under mechanical stress and thermal conditions.

Understanding, Predicting, and Controlling the Microbial Phenome

Our Goal: PNNL will decipher the molecular basis of the microbial phenome to advance function-driven design and control of microbial systems, enhancing our understanding of the living Earth system while also advancing the future of scalable biotechnologies.

The Challenge: The phenome is the collection of observable biological traits of an organism, shaped by the interaction of its genes with its environment (i.e., genotype + environment = phenotype). While the genome revolution has catalyzed breakthroughs in environmental science, medicine, and bioengineering, we currently cannot predictably engineer an organism for beneficial purposes. To identify the design principles of biological systems, we must measure the functional code of the cells, including proteins, small molecules, and lipids, whose production, structure, and function are dynamically regulated by environmental factors. Phenomic prediction hinges on the availability of this complementary environmental information.

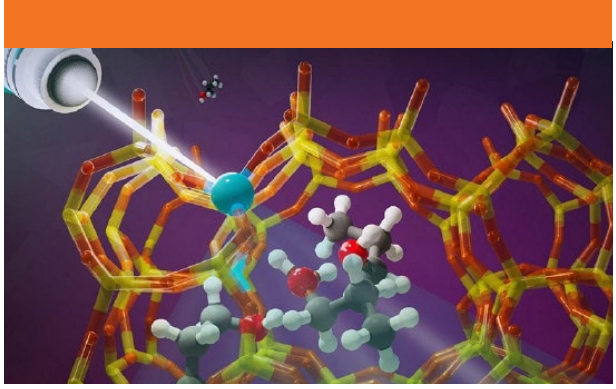
This research leverages PNNL's historical strengths in multi-omics technology and data science (e.g., proteomics, metabolomics, data analytics, and signature discovery) as well as the Laboratory's recent investments in measurement science, phenomics, and AI and machine learning.

Our Approach: Our predictive phenomics strategy has four scientific goals:

1. Characterize the molecular foundations of microbial traits.
2. Understand the role of microbes in Earth–energy system dynamics.
3. Advance and expand bioprocesses for the bioeconomy.
4. Develop new phenomic sensing platforms for monitoring microbial system health.

Recent Accomplishments: The Molecular Microbial Phenotyping Capability (M2PC), which will enable world-leading, automated microbial molecular phenotyping capabilities at PNNL, has passed its initial design phase and is set to begin construction in 2026.

Critical Partnerships: PNNL works closely with Lawrence Berkeley National Laboratory to advance our biosensing and synthetic biology objectives through the EMSL-Joint Genome Institute facilities, the Joint Bioenergy Institute, and the DOE-funded Agile BioFoundry. Our partnerships with other national laboratories and academic institutions are used to accelerate the development of deployable sensors, while leveraging PNNL's strengths in sensor system conceptualization and evaluation.



Transformational Catalysis for Chemical Conversions

Our Goal: PNNL will advance the state of the art of catalysis science and engineering across scales to accelerate the development of novel chemical processes to exploit alternative reagent streams and energy carriers.

The Challenge: Carbon is integral to the American economy, playing a key role as a fossil energy carrier for transportation and electricity generation. Carbon is equally essential in producing goods such as plastics, packaging, textiles, tires, and composites. However, current practices for developing new and better products—from inception to commercialization—take decades. New advances in AI and autonomy offer the opportunity to dramatically accelerate this process through the integration of AI with molecular theory, catalyst synthesis and testing, advanced in situ and operando spectroscopic techniques, and reactor codesign. This ability is essential to maintain U.S. preeminence compared to our international competitors.

This research builds on PNNL's acknowledged leadership among DOE laboratories in chemistry, spectroscopy, nuclear magnetic resonance, and data sciences, through our work at the Institute for Integrated Catalysis and in our state-of-the-art facilities such as the recently completed Energy Sciences Center.

Our Approach: PNNL will enable rapid acceleration in the development of new chemical processes and next-generation catalysts by:

1. Designing reactive separation processes for underutilized, domestic carbon resources.
2. Developing and integrating transformative technologies for accelerated catalyst design.

Recent Accomplishments: PNNL designed a new reactive separation that chemically upcycles waste lignin and lignite biopolymers, enabling their use in producing durable and economically competitive building composites. This innovation allows the use of domestically abundant, yet currently unconventional feedstocks such as waste plastic and coal or lignin, as new, secure supply chains for domestic manufacturing.

Critical Partnerships: PNNL currently is leading a collaboration among national labs—Ames National Laboratory, Argonne National Laboratory, Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, Oak Ridge National Laboratory, and SLAC National Accelerator Laboratory—to address this challenge. Additionally, we are broadening our strategic partnership with Microsoft and exploring opportunities with other potential stakeholders.

Earth and Energy System Dynamics

Our Goal: PNNL will develop and deploy dynamic digital testbeds that analyze the exposure, resilience, and growth potential of energy and related systems in the context of extreme events and complex multisectoral interactions.

The Challenge: Powering continued U.S. leadership in AI, quantum computing, advanced manufacturing, and other industrial sectors over the next decade is forecasted to require dramatic increases in domestic energy supply. Simultaneously, energy infrastructure, water resources, military facilities, and communities across the United States are all facing increasing costs and disruptions associated with extreme events. Our ability to predict, plan for, and protect critical assets and infrastructure is limited by an incomplete understanding of Earth system processes and coupled human–environment interactions, especially at regional-to-local scales.

This research leverages PNNL's capabilities in modeling multisectoral dynamics across scales, unique instruments such as single-particle mass spectrometers that can analyze the aerosol particle compositions that influence cloud droplet formation, and leading-edge computational approaches, including quantum computing techniques for simulating atmospheric turbulence and AI-guided uncertainty characterization.

Our Approach: PNNL's dynamic digital testbeds will leverage high-resolution modeling, new sources of data, and AI techniques to capture human–Earth system interactions—especially those related to the energy sector—with unprecedented detail in specific regions across the United States. We will also focus our research in three supporting areas:

1. Precipitation processes and the water cycle, which are inexorably linked to energy systems.
2. Human systems, including population dynamics and the factors driving energy system evolution.
3. Complex, multiscale interactions among energy, water, land, and other human and natural systems.

Recent Accomplishments: Through the PNNL-led Integrated Multisector Multiscale Modeling (IM_3) project, researchers are developing and coupling multiple high-fidelity process models to address electric grid performance during heat waves, the multisectoral impact of compounding droughts, and urban water demands.

Critical Partnerships: PNNL is steering several large, multi-institutional, interdisciplinary efforts involving other DOE laboratories and academic institutions to better understand important aspects of Earth systems and their implications for energy infrastructure and planning.

Digital Imperatives

PNNL is committed to building an integrated digital ecosystem that enhances our computational research capabilities while modernizing our business operations. In alignment with national strategic priorities, PNNL has identified six critical digital imperatives that will drive institutional advancements and position us to lead in the coming decade:

- **Artificial Intelligence:** PNNL will expand AI capabilities by integrating advanced machine learning techniques, deploying AI-enabled research platforms, and fostering strategic partnerships with industry leaders to accelerate discovery.
- **Automation and Autonomy:** PNNL will embrace the next frontier in laboratory operations through the use of AI-driven automation, enabling seamless control of experimental workflows, polyfunctional robotic process automation, and intelligent systems capable of autonomous scientific discovery.
- **Software Engineering:** PNNL will institutionalize modern software development techniques such as DevSecOps, AI-assisted coding, and automated software pipelines to enhance scalability, security, and efficiency across all software- and model-developing staff.
- **Data Stewardship:** Recognizing that data is a strategic asset, PNNL is developing robust data governance frameworks, enhancing metadata management systems, and deploying secure, scalable architectures to optimize research data use.
- **Continuum Computing:** By integrating cloud computing, high-performance computing, and edge computing, PNNL will build a dynamic environment that ensures seamless computational processing across multiple architectures, improving agility and efficiency.
- **Digital Business Transformation:** AI-driven digital platforms at PNNL will reduce operational complexity, improve efficiency, and enable real-time decision-making across laboratory functions, while providing a significant enhancement in the overall user experience.

To achieve these ambitious goals, PNNL is developing roadmaps that align mission needs with emerging technological advancements. These roadmaps will focus on three key areas: identifying priority research domains where digital capabilities can have the greatest impact, investing in cutting-edge platforms, and cultivating a multidisciplinary talent pool skilled in AI, software engineering, and computational research.

As digital technologies redefine scientific inquiry, PNNL is poised to lead the DOE laboratory complex in AI adoption, data-centric research, and autonomy. By addressing challenges such as data interoperability, AI governance, and cybersecurity risks, we will ensure a responsible and forward-thinking approach to digital transformation.

PNNL'S CAMPUS

Since its founding in 1965, PNNL has stewarded state-of-the-art research capabilities, ensured safe and secure operations, and delivered world-leading research and development to advance the mission priorities of DOE and other federal agencies. PNNL's commitment to excellence in science, technology, and laboratory operations has earned the Lab international recognition as a thought leader in many research fields.

Through strategic investments and collaboration with DOE and the State of Washington, PNNL continues to support cutting-edge research addressing national priorities by advancing a modern and adaptable campus. Over the next decade, PNNL's

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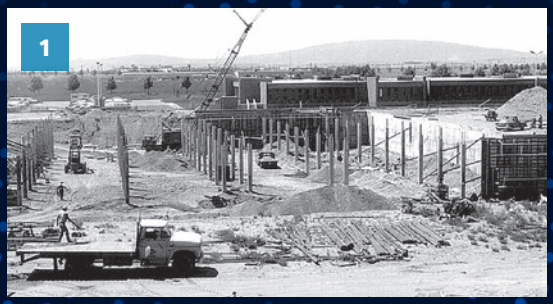
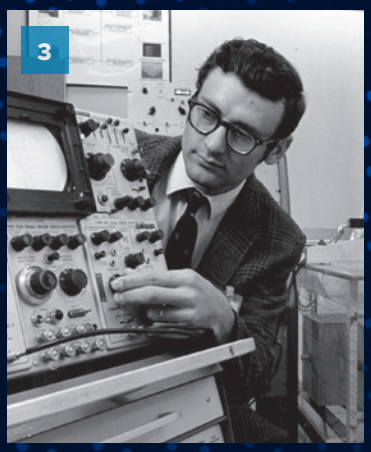
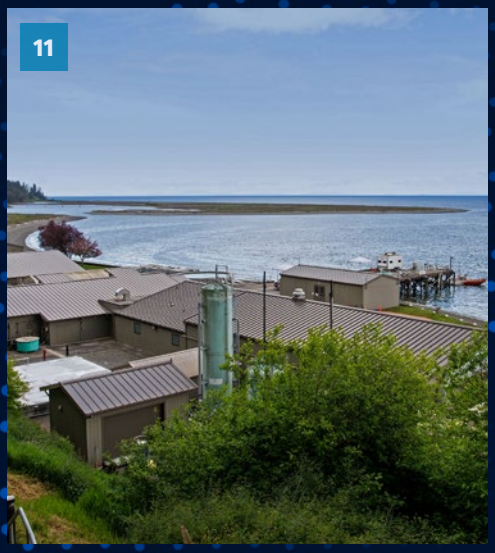
1965 – 2035





campus strategy will focus on modernizing its facilities and infrastructure to meet evolving scientific and operational demands to drive advancements in energy resilience, national security, and fundamental science while maintaining flexibility in response to future challenges.

IMAGES SHOWN: **1.** Construction of First Buildings **2.** Research Operations Building **3.** Early PNNL Research **4.** Shallow Underground Laboratory **5.** Biological & Computational Sciences Facility **6.** Environmental Molecular Sciences Laboratory **7.** Discovery Hall **8.** Electricity Infrastructure Operations Center **9.** General Purpose Chemistry Laboratory **10.** Energy Sciences Center **11.** PNNL-Sequim **12.** Grid Storage Launchpad **13.** Rendering of Microbial Molecular Phenotyping Capability **14.** Site Plan for New National Security Complex **15.** Rendering of New Secure Physical Sciences Facility **16.** Rendering of New Advanced Secure Communications Facility



PNNL By The Numbers

(2024 DATA)

$1.64B
Annual spending

2,297
Active S&T projects

6,437
Scientists, engineers, and professional staff

1,672
Peer-reviewed, published articles

319
Invention disclosures

3,213
U.S. and foreign patents since 1965

87 Structures with a combined **~2.6M** square feet

1,035
Students engaged

211
Companies with PNNL roots—IP or expertise since 1965

781
Total campus acres
644 / RICHLAND, WA
117 / SEQUIM, WA

50+
Agencies supported

220+
Joint appointments with top academic institutions

PNNL is a Department of Energy Office of Science Laboratory, operated by the Battelle Memorial Institute.

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