FUNDAMENTAL SCIENCE: CRITICAL TO MEETING U.S. ENERGY AND CLIMATE MITIGATION GOALS

NATIONAL LABORATORY
DIRECTORS' COUNCIL

JANUARY 2021

Breakthroughs in fundamental science are prerequisite to the development of transformational technologies at scales large enough to meet the grand climate and energy challenges facing the nation. As the United State's largest funder of the physical sciences and through its stewardship of 17 National Laboratories, the Department of Energy (DOE) has a unique and central role to play in helping the new Administration meet its climate change mitigation and energy targets.

While current, near-term approaches to climate change mitigation and clean energy solutions should be pursued aggressively, existing technologies do not scale adequately to meet the ambitious goals and objectives of the incoming Administration in the long-term. The challenge goes well beyond current technology; it requires fundamental science discovery of novel phenomena and materials that enable entirely new technologies for achieving net-zero greenhouse gas emissions by 2050. As opposed to applied research, which seeks to advance or improve known technologies, fundamental science and discovery seek to add to our basic understanding of the materials, molecules, and processes that make up our world.

The National Laboratories are designed to tackle complex problems, both in the near and long-term, by leveraging world-leading scientific capabilities and expertise, and through the full utilization of their national scientific user facilities. These facilities, large-scale and often one-of-a-kind, are available to the nation's research community broadly and support all federal research agencies, as well as industry (36,000+ researchers from across the nation and the world in 2019). The DOE, through collaborations among National Laboratories, universities, and industry also supports world class research centers, hubs, and grant programs focused on fundamental science to speed the delivery of critical energy and climate change mitigation solutions. Many of these programs are well-established and already contributing significantly to these grand challenges.

DOE has a proven track record of bringing fundamental science to complex societal challenges and of speeding the delivery of solutions to society. As part of the Human Genome Project, DOE was the first to deliver on the project's promise, decoding the sequences of three important human chromosomes. Structural biology expertise and x-ray crystallography capabilities at DOE light sources speed the delivery of drug discovery. These accomplishments and resources provided much of the foundation for the development of CRISPR, 2020's Nobel Prize winning gene editing tool, and contributed significantly to today's mRNA-based COVID vaccines. Furthermore, fundamental materials and chemistry breakthroughs drove a factor-of-ten decrease in lithium-ion battery prices over the last decade. And fundamental theoretical, materials, and physics research advances are driving quantum information science applications, including encryption strategies for cyber and grid security.

Even as the climate crisis intensifies, the United States possesses at its disposal the expertise, resources and strategic avenues to address it. At this moment of change and uncertainty, the federal government must fully leverage all of its fundamental science assets, build upon existing climate change mitigation and energy research and development, and break down barriers among federal assets to increase the return on investment and create new pathways for exploration and fundamental discovery.

The critical thinking and creativity of fundamental science are required to gain understanding at a systems level and lay the groundwork for new game-changing technologies needed to meet the challenge. Although not exhaustive, here are a few examples for which DOE has significant resources and expertise:

- Experimentally measuring and modeling the earth's climate system at exponentially higher fidelity and finer scales to provide a fuller understanding of the challenge and to better inform the delivery of innovative solutions at scale;
- Critical and sustainable materials discovery to advance clean energy technologies, i.e., batteries, wind, solar, and clean hydrogen, and also advanced carbon capture and utilization at scale;
- Engineering biology and biotechnology to develop clean solutions to difficult challenges such as drop in sustainable aviation fuel, bioproducts that sequester carbon indefinitely, and sustainable replacements for plastics and other environmentally harmful products.

How the DOE National Laboratories Fit in: At the Energy-Climate Nexus

This broad and deep expertise coupled with the ability to quickly form large, interdisciplinary teams is found few places in the world, but the Department of Energy's 17 National Laboratories are some of them. DOE's current investment in basic science, through the Office of Science and its $7B budget, already returns tremendous dividends on taxpayer investment. The Office of Science is particularly well suited to leverage fundamental science to address today's technology gaps and accelerate progress toward systems-level solutions. Breakthroughs provided by fundamental science fuel our economic prosperity, national security, and international competitiveness.

Beneficial innovation often arises unpredictably from a strong ecosystem of scientific investigation. Therefore, we need to sustain and steward fundamental science across disciplines in order to strengthen foundational capabilities, explore new horizons, and facilitate accelerated impact, ultimately leading to wholly new technologies to address climate and energy challenges as an integrated system. In a companion white paper *(Science to Accelerate Solutions to U.S. Energy, Climate, and Environmental Equity Challenges),* we describe four specific opportunities and associated roadmaps to (1) Advance Energy Storage Technologies; (2) Accelerate Discovery of Net-Zero Materials, Chemicals, and Manufacturing Processes; (3); Advance Integrated Human-Earth Systems Modeling for Science-Based Decision Making; and (4) Develop an Integrated Land-based Negative Emissions Bioenergy Economy.

STRENGTHEN FOUNDATIONAL CAPABILITIES

The climate and energy challenges we face require interdisciplinary approaches and cross-domain solutions, outlined as over-the-horizon challenges by the collective Directors of DOE's National Laboratories. Ongoing DOE funded research is advancing the frontiers of artificial intelligence and machine learning, quantum information science, biotechnology (toward a bio-economy), manufacturing science, and microelectronics research, as well as other areas in foundational physical, biological, and computational sciences. These critical research programs underpin our ability to address current climate and energy challenges and ongoing national and economic security needs and must continue.

DOE's National Laboratories also host world-leading user facilities that provide world-class scientific capabilities to the entire research community on a competitive, peer-reviewed basis. These facilities are unique not just in the tools they provide, but in the access to world-leading expertise among the National Laboratory staff at these facilities. These are vital resources for accelerating scientific discovery, supporting American innovation through partnerships with industry, and supporting STEM workforce development. Across the 17 National Laboratories, researchers can gain access to light sources, neutron sources, particle accelerators, nanoscale science research centers, microscopy centers, environmental research facilities, and high performance computing and data-analytics resources their home institutions could not provide on their own.

These facilities have opened up new avenues to characterize and model phenomena and processes that are central to understanding climate change and energy systems at unprecedented length scales and speeds. The demand for these facilities by the research community far exceeds availability — by 300 to 500 percent, or more. Over the past year, DOE also has recognized additional opportunities to enhance facility access via remote utilization and enhanced availability to under-represented communities.

Both the research demand for accessing these resources and competition for global leadership in these technologies has accelerated in recent years. The Department has developed roadmaps for upgrading and building new user facilities across the lab complex and Congress has passed legislation supporting these efforts to secure continued global leadership. These new and upgraded facilities would provide revolutionary capabilities to the research community, including integration of simulation and observation/measurement of phenomena at time and length scales that are central to addressing the climate change challenge. Without investment, we will cede leadership in these technical capabilities to our international competitors and watch the research and industrial community flock to better, more accessible facilities elsewhere, taking innovation capacity with them.

EXPLORE NEW HORIZONS OF KNOWLEDGE

The seed corn for future discoveries, disruptive technologies, and solutions to societal challenges — including climate change and clean energy technology development — originates in new ideas and, often, new researchers. Historically, research at the frontiers of foundational disciplines has been under-resourced relative to larger-scale initiatives and facility needs. Other countries have significantly increased investments in R&D expenditures to the point where the United States is no longer viewed as the consensus global leader in science.

Redoubling emphasis on fundamental science is essential for keeping our pipeline of innovative clean energy solutions full for the decades it will take to tackle the climate crisis at scale. And in so doing, we will safeguard our future economic and national security and ensure U.S. leadership, including through international collaboration. Greater focus on fundamental science research also signals to today's diverse student body that there is a secure and exciting future in STEM. We should take care to ensure that the expanded workforce that results is built by inclusively drawing from the entire American community — starting at the regional level, led by the National Laboratories.

Effective investment in these areas requires robust strategic planning to define where challenges lie, while not constraining discovery space. DOE's Office of Science, through its independent advisory committees and community-based basic research needs workshops, has already defined and documented important research frontiers. In areas spanning advanced scientific computing research, basic energy sciences, biological and environmental research, fusion energy sciences, high energy physics, and nuclear physics, as well as accelerator and isotope R&D and production, the Office of Science has developed roadmaps that point the way to a healthier, more sustainable, and more prosperous future.

ACCELERATE THE PACE AND IMPACT OF DISCOVERY

Accelerating the pace and impact of discovery science will require effective leadership and planning to ensure prudent stewardship of taxpayer resources, appropriate agency coordination, and inclusive participation from the broad research community. This is especially true when responding to urgent interdisciplinary and cross-domain challenges such as clean energy technology development and climate change. To foster effective acceleration, we offer several specific suggestions that the DOE and its National Laboratories facilitate and lead:

- Engaging the research community inclusively on priority topics in the short- and long-terms through roundtables, basic research needs workshops, and other strategic planning mechanisms.
- Establishing "All of DOE" coordination mechanisms to identify unique capabilities and define common objectives and collaboration strategies across programs for the accelerated translation of relevant discoveries to societal impact.
- Defining "All of Government" imperatives — building on the successes of the National Nanotechnology Initiative, National Quantum Initiative and National Strategic Computing Initiative — in response to our climate and energy challenges.

DOE and its Laboratories have a track record of leveraging their deep scientific expertise to rapidly respond to pressing national challenges. Since their founding in the Manhattan Project to today, DOE National Laboratories' scientific expertise, capabilities, and facilities have responded to many national crises.

Most recently, the National Laboratories came together through the National Virtual Biotechnology Laboratory (NVBL) in response to the COVID-19 pandemic. In a matter of weeks, the NVBL helped drive research that mitigated shortages in medical supplies, modeled and predicted pandemic spread, improved and validated testing procedures, assessed the transmittal of the virus in buildings, and supported the development of new antiviral drugs.

The Laboratories have also come together to address climate and energy emergencies, such as responses to the Deep Water Horizon, Aliso Canyon, and Fukushima events, as well as myriad hurricanes and other natural disasters. In each case the Laboratories acted urgently, with breakthrough discoveries and impactful solutions developed hand-in-hand. Through a coordinated response, the Laboratories contribute to both mitigating the immediate crisis and better preparing the country for future challenges.

Conclusion

The National Laboratories, along with their university and industry partners, can bring the necessary expertise and capabilities to addressing the climate and energy crisis. These challenges will not be solved quickly with existing technologies, but require focused, sustained investment in fundamental science to support continued innovation long into the future. By strengthening mission-driven fundamental science in a manner consistent with the magnitude and urgency of our energy and climate challenges, we as a society can truly realize the vision of building back better.

LABORATORIES AND DIRECTORS (AS OF JANUARY 2021)

DOE LABORATORY CONTRACTOR	DIRECTOR
Ames Laboratory Iowa State University of Science & Technology	**Adam Schwartz**
Argonne National Laboratory (ANL) UChicago Argonne, LLC	**Paul Kearns**
Brookhaven National Laboratory (BNL) Brookhaven Science Associates, LLC	**Doon Gibbs**
Lawrence Berkeley National Laboratory (LBNL) University of California	**Michael Witherell**
Fermi National Accelerator Laboratory (FNAL) Fermi Research Alliance, LLC	**Nigel Lockyer**
Idaho National Laboratory (INL) Battelle Energy Alliance, LLC	**John Wagner**
Los Alamos National Laboratory (LANL) Triad National Security, LLC	**Thom Mason**
Lawrence Livermore National Laboratory (LLNL) Lawrence Livermore National Security, LLC	**William (Bill) Goldstein**
National Energy Technology Laboratory (NETL) Government-owned, government-operated	**Brian Anderson**
National Renewable Energy Laboratory (NREL) Alliance for Sustainable Energy, LLC	**Martin Keller**
Oak Ridge National Laboratory (ORNL) UT-Battelle, LLC	**Thomas Zacharia**
Pacific Northwest National Laboratory (PNNL) Battelle Memorial Institute	**Steven Ashby**
Princeton Plasma Physics Laboratory (PPPL) Princeton University	**Steve Cowley**
Sandia National Laboratories (SNL) National Technology and Engineering Solutions of Sandia, LLC	**James Peery**
Savannah River National Laboratory (SRNL) Savannah River Nuclear Solutions, LLC	**Vahid Majidi**
SLAC National Accelerator Laboratory Stanford University	**Chi-Chang Kao**
Thomas Jefferson National Accelerator Facility (TJNAF) Jefferson Science Associates, LLC	**Stuart Henderson**
NLDC Secretariat	**Julie Wulf-Knoerzer**

CONTACT

Doon Gibbs
Chair
National Laboratory Directors' Council
Email: gibbs@bnl.gov