ENSURING AMERICAN LEADERSHIP IN MICROELECTRONICS

A Hearing of the Committee on Science, Space, and Technology
U.S. House of Representatives

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Introduction

Chairwoman Johnson, Ranking Member Lucas, and distinguished Members of the Committee, thank you for holding this important hearing and for inviting me to provide testimony. It is addressing one of the most important economic challenges the nation is facing, one that I have been speaking about for several years. I am heartened by the Committee's and Congress's focus on it - particularly on the important role that the Department of Energy can play in maintaining this critical capability for the economy and for national security.

I am Mike Witherell, Director of the Lawrence Berkeley National Laboratory. Founded in 1931 on the belief that the biggest scientific challenges are best addressed by scientists and engineers working together in teams, Berkeley Lab and its scientists have been recognized with 14 Nobel Prizes and 15 National Medals of Science. Today, Berkeley Lab researchers develop sustainable energy and environmental solutions, create novel materials, advance the frontiers of computing, and probe the mysteries of life, matter, and the universe. Scientists from across the United States and around the world rely on the Lab's facilities for their own discovery science. The Lab is a multiprogram national laboratory, managed by the University of California for the U.S. Department of Energy's Office of Science.

I've been Berkeley Lab's director since 2016, and was previously director of Fermilab from 1999-2005. I also served as Vice Chancellor of Research at the University of California Santa Barbara for ten years. Over the past two decades, I have become more and more concerned about the increasing threat to the nation's leadership in semiconductors. Strengthening the nation's entire microelectronics ecosystem - research, technology development and commercialization at scale - is imperative for the nation. And to address that threat adequately, as representatives of the semiconductor industry have repeatedly pointed out, requires a whole-of-government approach. Every national asset must be deployed and all resources and activities must be well coordinated. It really is the time for an “all hands-on deck” approach that requires new investments across the innovation ecosystem – industry, academia, and the Department of Energy national laboratories.

Background

After over eight decades of federal investment in research and development at the national laboratories and universities, the Department is today the largest supporter in the U.S. of the physical sciences and is the national leader for research in the fields that underpin microelectronics: physics, chemistry, materials science, and computer science. As a measure of this impact, over one hundred Nobel prizes have been awarded to scientists affiliated with the Department of Energy and its laboratories. Because of this leadership in research and the unprecedented facilities and capabilities available for solving national problems, DOE and its national laboratories are well prepared and uniquely outfitted to continue to play a key role in the nation’s microelectronics ecosystem.

The DOE is a mission-focused agency, focusing on advancing the national interest in energy solutions, environmental sustainability, and national nuclear security. The fourth core mission of the Department is supporting the basic science that underpins and enables advances across the Department's other core mission areas. DOE and the national labs have it in their DNA to work in broad, multidisciplinary teams to meet objectives and address technology challenges that require a sustained R&D effort.

Because of DOE’s mission focus and extraordinary research capabilities, the Department and its national laboratories have successfully tackled several grand scientific national challenges, like the Human Genome Project and the development of innovative battery technologies. A unique signature of the DOE national labs is their ability to encourage, incentivize, and facilitate a tightly managed team science approach to address national challenges with the urgency they demand. They also have a proven ability to protect national security and economic interests.

Everyone arguing for a national campaign to recapture international leadership in microelectronics recognizes that the semiconductor industry has the central role. But, we also know that success requires an ecosystem of national assets supporting industry. The national laboratories bring to this ecosystem a unique capability to design, build, and steward world-leading, large-scale scientific user facilities. These facilities include the world’s most powerful supercomputers, tools that can image individual atoms in 3-D, and unique genomic and biomolecular research facilities. And they are available to support researchers from all components of the nation’s research ecosystem -- academic, federal, and private industry. Over 36,000 researchers annually, many funded by agencies across the federal government, including NIH, NSF, NASA, and USDA, and by industry and foundations, use the national laboratories' facilities to conduct their research and technology development.

The DOE Role

Why should DOE have a major role in the national microelectronics initiative? I have just argued that the mandate to meet the DOE's mission objectives has led the national laboratories to develop highly managed teams of the world's best scientists and unique large-scale research facilities. The national laboratories contribute a unique array of assets to the science-to-systems ecosystem needed for this national campaign. And because of the federal investments made at the national laboratories over decades, these assets can be deployed immediately to help meet the current microelectronics challenge.

I have already discussed the leadership role that DOE holds in the fields of science and engineering that underlie microelectronics. In addition, the DOE national laboratories already have a long history of working together with the semiconductor industry on pre-competitive research that has helped push the boundaries of what chips can do and contributed to extending the life of Moore's law.[1] For example, the EUV lithography development facility at Berkeley Lab has been supported as a public-private partnership for more than two decades, with continuing investment from semiconductor industry partners. As a Lab Director, this investment sends me a clear confirmation that we are providing R&D services that are valuable to this industry.

In addition, the continuation of microelectronics' evolution along the path of business as usual would require an unsustainable amount of the world's energy budget. Although microelectronics make up around 5% of the world's energy consumption today, the current trajectory would put it at around 25% by 2030.[2] We cannot meet the national energy goals without addressing the future of microelectronics. Conducting research to dramatically improve the energy efficiency of microelectronics is a science and technology challenge that falls squarely within the DOE's energy mission space.

For those who understand the capabilities and history of the DOE, it is clear why and how the national laboratories can, and if given the opportunity, will make unique and profound contributions to addressing the microelectronics challenge. The Department

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[1] Sparking Innovation: How Federal Investment is Semiconductor R&D Spurs U.S. Economic Growth and Job Creation. Report Supplemental: Appendice C., p. 13

[2] Decadal Plan for Semiconductors, Chapter 5, page 18, SRC 2020.

and its Laboratories have had a transformative impact on the global development of a wide range of strategic technologies, including energy storage, structural biology for medical research, genomics, and space propulsion.

The DOE strength in scientific research enables foundational discovery across a broad landscape that is focused on overcoming the barriers to technological advancement. Although we don't know the detailed designs for future generations of semiconductors, we do know that they will need new materials, novel devices, and even new algorithms. We also know from experience how we can help accelerate the design-build-test-learn cycle by which we translate new science-based technologies to commercialization.

The DOE labs contain the largest collection of nanoscale materials synthesis and characterization capabilities in the US at their user facilities. The Nanoscale Science Research Centers (NSRCs) offer extensive extreme scale nanofabrication tools and are DOE's premier user facilities for interdisciplinary research to understand and control matter at the nanoscale, serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. The DOE's x-ray light sources, neutron sources, and electron microscopes have unmatched capabilities to characterize materials and microelectronic devices. Taken together, these facilities would bring to the microelectronics initiative:

- the ability to rapidly develop novel materials with transformative electrical properties;
- a deeper understanding of quantum systems and their promise to transform computing; and
- imaging of atomic organization and chemical interactions at unprecedentedly small scales to advance more efficient devices for information processing and storage.

In addition to these remarkable facilities, the DOE laboratories have established R&D hubs and centers custom-designed to work with a specific industry sector to accelerate the cycle that translates innovations into mature technologies ready to be incorporated into products that can compete in the marketplace. The collaborative Team Science approach is successfully applied in multi-laboratory research institutions like the Joint Center for Energy Storage Research led by Argonne, the Liquid Sunlight Alliance led by Caltech, and the Critical Materials Hub led by Ames National Laboratory. The DOE Bioenergy Research Centers, including the Joint BioEnergy Institute (JBEI) at Berkeley Lab, have a remarkable record of moving biotechnologies to industry. To take just a single example, JBEI has generated intellectual property that has resulted in 99 issued patents, 150 licenses to industry, and 11 startups. Such R&D hubs do not replace industrial laboratories, but rather they give a competitive advantage to those aligned with the national economic interest. This approach would add an extra boost to the national microelectronics campaign.

DOE also has recently developed new capabilities and resources that use data science and artificial intelligence to accelerate the materials discovery process. A trailblazing example of this is the Materials Project at Berkeley Lab. The Materials Project harnesses high performance computing for high-throughput searches for new materials - increasing throughput for discovering new electronic materials and devices by a factor of 1000x over current methods. With more than 220,000 users, over 10,000 daily unique visitors to the site and millions of data records demanded and delivered daily (average around 2M; peaks around 45M) the Materials Project is the world's most popular and utilized online materials research tool. Applied to the microelectronics challenge, researchers would more quickly and efficiently identify ideal candidate materials to help reduce the energy consumption and improve the efficiency of semiconductors.

The proposed National Semiconductor Technology Center (NSTC) is envisioned as a large, distributed center supported by several federal agencies to conduct research and prototyping of advanced semiconductor concepts in partnership with the private sector. The DOE laboratories have the capability to translate newly developed materials and process innovations into test devices and then scale them to the point that they can be fed into the chip-level processing at the NSTC. The national laboratories will be central players in setting up a pipeline that can accelerate the translation from science and engineering to technologies ready for demonstration at industrial scale.

Public-Private Partnerships

There is a long history of public-private partnerships at the national laboratories. Several technology industries understand the value proposition in taking advantage of the national laboratories for their research and technology development programs. As I have already shown, the steady investment by the federal government has produced national laboratories that have an unprecedented combination of broad scientific expertise, state-of-the-art facilities, and a highly managed approach to mission-critical R&D. Many industry sectors have formed sustained partnerships with the laboratories, using them as a force multiplier to become more competitive.

Industry also widely views the national laboratories as objective and neutral, since it is part of our mission to work in an even-handed way with all federally-approved private partners. Notable examples of successful public-private partnerships at the national laboratories include the previously mentioned work with the semiconductor industry, as well as sustained partnerships in high performance supercomputing, advanced battery research, and pharmaceutical research and development.

Several facilities and key expertise have been developed at DOE laboratories to support the semiconductor industry's existing capability to fabricate devices with feature sizes of several nanometers. As referenced previously, semiconductor companies, working collaboratively at Berkeley Lab, have made over $90 million in investments at the Advanced Light Source to shrink the size of chips to widths and depths of a few dozen atoms by using extreme ultraviolet (EUV) lithography. Argonne National Laboratory offers extreme scale device processing at the Center for Nanoscale Materials, one of DOE's five Nanoscale Science Research Centers mentioned earlier. The MESA Fab complex at Sandia National Laboratories develops and maintains core semiconductor processing capabilities and capacity needed to support the DOE's nuclear security mission. Another example is how industry and academia are partnering with and leveraging Princeton Plasma Physics Laboratory and its expertise in plasma science to to meet the present and future challenges of semiconductor device fabrication. Low temperature plasmas are essential tools in semiconductor chip manufacturing.

In addition, the world-leading advanced x-ray light sources at DOE laboratories enable researchers to characterize with high precision the new materials and novel devices needed for ultra-efficient computing. Completing the cycle of technology development requires the computer modeling capability available at the DOE's High Performance Computing (HPC) facilities, in addition to specialized software and applications developed specifically to take advantage of these unique computing platforms. To keep the U.S. internationally competitive in high performance computing, the DOE and the national laboratories have successfully partnered with industry suppliers to co-design entirely new generations of supercomputing systems through projects such as the Exascale Computing Project. In these public-private partnerships, industry provided matching funding for DOE's investments and lab scientists and facilities have been tightly integrated into those efforts.

Finally, the pharmaceutical and biotech industry have a long and productive partnership with several national laboratories. Industry leverages the x-ray light sources at the labs for imaging proteins to advance drug discovery and speed the drug development pipeline. At Argonne and Berkeley Lab, the pharmaceutical industry has invested more than $130 million over the past 20 years in capital investments, including crystallography beamlines, and in direct research support.

STEM Workforce

I would also like to emphasize the importance of developing the highly trained workforce needed to keep the nation’s standing as a global leader in microelectronics. The Departments of Materials Science and of Electrical and Computer Engineering at U.S. universities are the best in the world. But they will need to scale up their programs to train many more graduate students who have hands-on experience with the new technologies needed for the future of microelectronics. The DOE national laboratories employ over 5000 of the nation’s best graduate students and postdoctoral researchers, enabling them to work on these strategic technologies and exposing them to the world-class instrumentation and facilities at the labs. To continue as the global leader in microelectronics, the nation will have to make an investment in developing the talented scientists and engineers who will forge this revolution.

Conclusion

In conclusion, a successful and efficient effort to harness the power of the U.S. federal research enterprise to drive dramatic gains for the microelectronics industry will fully leverage the existing tens of billions of dollars of investments at the national laboratories and will make strategic, new investments in their capabilities and facilities. Appended to this testimony is a joint national laboratory response to a 2018 DARPA Request for Information. This document provides more examples of capabilities at the national laboratories that may advance the nation’s quest to regain international microelectronics leadership.