Testimony of

Adam J. Schwartz

Laboratory Director, U.S. Department of Energy Ames Laboratory

Professor of Materials Science and Engineering, Iowa State University

Ames, IA 50011

Before the

Joint Subcommittee on Energy and Subcommittee on Research and Technology

of the

Committee on Science, Space, and Technology

U.S. House of Representatives

Materials Science: Building the Future

June 28, 2017

Chairman Weber, Chairwoman Comstock, Ranking Members Veasey and Lipinski, and Members of the subcommittees, thank you for the opportunity to testify at this hearing and thank you for your continued strong support of materials research. I am pleased to have the opportunity to discuss building the future of materials science. I am Adam Schwartz, director of Ames Laboratory, a Department of Energy national laboratory located on the campus of Iowa State University, in Ames, Iowa. Ames Laboratory is a single program Office of Science laboratory with the mission to create materials, inspire minds to solve problems, and address global challenges. I am also a professor of Materials Science and Engineering in the College of Engineering at Iowa State University. Before arriving at Ames Laboratory 3 years ago, I was division director for the Condensed Matter and Materials Division, acting program leader for the Dynamic Properties of Materials and the Physics and Engineering Models Programs, and led the plutonium aging program during my nearly 23 years at Lawrence Livermore National Laboratory, a National Nuclear Security Administration national laboratory in Livermore, CA.

The United States is the world leader in materials science, condensed-matter physics, and chemistry research. Federal investment in academia, national laboratories, and scientific user facilities—core materials science research supported by both the Department of Energy and the National Science Foundation—has created an innovation system that is unmatched anywhere in the world, including the private sector. Our leadership is due in large part to materials science funding across the continuum, from grand challenge and use-inspired basic research to applied research and technology deployment. As a result, the U.S. leads in discovering and applying new materials with novel properties. As a country, we've reaped tremendous benefits in economics, energy security, national security, and our quality of living.

The Department of Energy national laboratory system created after the end of the Manhattan Project successfully built upon and greatly expanded materials research and development expertise that was critical to the Project's success. Today, this unparalleled expertise remains unmatched and our country's national laboratories constitute their own unique facilities and research strengths, and working together to contribute significant technological advances in the national interest. Fundamental and highly specialized expertise in the synthesis of materials; theory, modeling and simulation; as well as materials characterization and development across the national laboratory network are collaboratively brought to bear on solutions to complex scientific challenges. Ames Laboratory and other national laboratories breed materials innovations that over and over again lead to revolutionary technologies.

Materials Discoveries Have Impact: Lead-free Solder

At the close of the 20th century, the production of electronics boomed as personal electronic devices such as computers and mobile phones became staple household items. As the production of electronics expanded, so did concerns about electronic waste and its potentially harmful environmental effects, particularly with the use of leaded solders required to fuse electronic components together. In the mid-1990s, the electronics industry set a goal of halting the use of lead-based solders due to their harmful effects on people and the environment. Research to find a lead-free solder increased in response to this goal.

Lead-free solder, developed at the Ames Laboratory in collaboration with Sandia National Laboratory, is a tin, silver, and copper alloy that is low melting and applies easily, at a reasonable cost. This revolutionary solder alloy replaces many uses of the traditional tin-lead low melting solder, reducing further the number of lead toxicity hazards in our everyday environment. This advanced alloy was ultimately licensed to over 65 companies in 23 countries with an economic benefit to the private sector estimated at $610M per year and is a key component in manufacturing mobile phones, tablets, and almost every consumer electronic device. It has generated approximately $60 million in royalty income, making it the top all-time royalty generator for Ames Laboratory and Iowa State University and one of the top for the U.S. Department of Energy. It is the only invention in the national laboratory complex that has returned revenue to the U.S. Treasury, approximately $6M.

Materials Discoveries Have Impact: Spinoff companies

Basic research discoveries at Iowa State University and Ames Laboratory have resulted in spinoff companies that demonstrate the power of federally funded research across the continuum of science. Research at Iowa State University and Ames Laboratory found that co-locating catalysts and their supports in confined spaces greatly increases reaction rates. That discovery led to a new series of bi-functional mixed metal oxide materials for a new type of catalysis - cooperative catalysis. Further research identified these new materials as ideal for biodiesel production. Starting with funding from DOE Basic Energy Sciences, then from Energy Efficiency and Renewable Energy, this new material attracted investor capital and Catilin, Inc. was born. A number of years later, a U.S. multi-billion dollar company bought Catilin and brought the catalyst to market.

For nearly 30 years, Ames Laboratory has also been a pioneer in the development of metallic powders, first for use in powder metallurgy, and now for use in 3D printing. Advances in the fundamental understanding of powder processing led to numerous patents and ultimately the spinoff of Iowa Powder Atomization Technologies, IPAT, with the goal to create high purity titanium metal powders that can be formed into industrial parts for military, biomedical, and aerospace applications. Using gas atomization nozzles and pour tubes developed at Ames Laboratory, the titanium powder making process is more efficient than anything known in the past and, thus, lowers the cost of the powder. IPAT was acquired three years ago by a different U.S. multi-billion dollar company and now makes commercially available titanium powders.

Great Opportunities Abound in Materials Research

Just like lead-free solder, cooperative catalysts, and metallic powders, great future opportunities exist to impact our world. New experimental and computational capabilities, developed from sustained federal investment in a talented and dedicated scientific workforce, have accelerated the pace of discovery of novel materials and changed the lives of every American for the better. We can now design and create materials tailored for some specific purposes and soon will be able to do so much more broadly with appropriate research support. The time is right to grow this capability because the nation's economic, energy, and security future relies on the discovery of advanced materials for efficient energy conversion, generation, and transmission.

Refrigeration and air conditioning

Modern civilization is highly dependent on reliable refrigeration and air conditioning and yet, we still use a vapor-compression technology that has remained essentially unchanged for over 100 years to provide vital societal needs ranging from food supply to medical treatment. Just like fluorescent and LED lighting transformed a century old industry that hadn't advanced since Edison's incandescent bulb, research of new materials to replace current compressed-vapor refrigeration technology could potentially reduce our energy consumption by one quarter.

Over the past century, all parts of a conventional refrigerator were refined due to concerted research and development efforts. Future improvements, however, may only be incremental since vapor-compression refrigeration is already near its fundamental limit of energy efficiency. Yet residential and commercial cooling still consumes one out of every five (or more) kilowatt-hours of electricity generated in the U.S.

New technologies with a potential to save a substantial fraction of the estimated 20 to 25% of the generated electricity used for cooling, refrigeration, and air conditioning in the U.S. will make a tremendous impact on our nation's energy future and ensure lasting business competitiveness and leadership in the industry, which is projected to double over the next 5-7 years to over $120B annually. Caloric cooling is a revolutionary, early-stage, solid-refrigerant technology making use of quantum effects that approach ultimate efficiency. Numerous system-level studies have predicted as much as 20 to 30% higher electrical energy efficiency for caloric-based refrigerators compared to the conventional vapor-compression systems. Solid-state caloric cooling today is analogous to where conventional refrigeration was in the 1920s, at the edge of a major breakthrough relying on the discovery and development of advanced materials.

Caloricool™ was established in 2016 as a DOE Energy Materials Network Consortium led by Ames Laboratory, as a collaboration of national laboratories, universities, and industry, to discover critically needed high-performance solid refrigerant materials that are earth-abundant, safe, manufacturable, and affordable. The consortium seeks novel materials that will meet or exceed the performance of conventional coolants and can be accepted by U.S. manufacturers for deployment within five to ten years.

Information technology

Amazing opportunities also exist in information technology. For decades, the computer industry has operated under Moore's Law, which predicts the density, speed, and power of integrated circuits increases exponentially over time. But the state-of-the-art in computing power is rapidly approaching theoretical limits of the materials that make up the heart of our computers and processors.

While increases in computational power have followed Moore's Law, the limitations of materials are causing an increase in energy costs for modern scientific computers that eventually will make supercomputers impractical because of enormous energy consumption and the need to dissipate massive amounts of heat. The density of transistors has approached atomic spacing, speed has plateaued, and the energy required to run systems is rising sharply. Industry can't indefinitely continue to cram more transistors onto chips.

To go beyond Moore Computing, research is needed to create new quantum materials and chips that use much less electricity, or even energy other than electricity, for example magnetic field or light, to control transistors and provide computing power and support communications far beyond today's approaches with conventional silicon chips. Targeted and well-focused fundamental research in materials and materials structures underpins the development of these new frontiers.

The goal is to discover and develop materials that enable very low power consumption per instruction. In order to realize this goal, new materials and materials structures controlled with low fields are required. Independent of the particular materials structure or structures, there are fundamental problems that cut across. First, how do we move electrons at nanometer length scales and make them respond at picosecond (one trillionth of a second) timescales in inhomogeneous nanoscale structures? Next, how do we ensure thermal stability? Third is how do we develop materials that will enable low energy transistors? Finally, how do we synthesize and integrate new materials into manufacturable architectures?

No suitable materials solutions exist today, but there are various potential materials systems that form a basis for both near and long-range roadmaps, and opportunities for expanding materials science understanding and consequent development efforts. Materials that are more developed for information technology applications and, therefore, could yield near term partial solutions include superconducting materials, organic materials, magnetic semiconductors, and materials for spintronics logic. Materials in their more nascent stage of understanding and development, but that could ultimately provide superior performance, include those that can be switched at will between conducting and insulating states and topological matter.

Critical Materials

Throughout the history of humanity, every civilization, including ours, revolved around materials that were discovered and put to use at the time. If any one of the materials required to make a product in high demand is suddenly no longer available, or in other words becomes critical, life undergoes changes that in the past were often catastrophic, unless a society foresees and addresses the shortage ahead of time.

The Critical Materials Institute, a DOE Energy Innovation Hub established in 2013, is conducting early stage research to accelerate the search for and establish alternatives to rare earth materials for a large range of advanced technologies, both reducing environmental impact and the nation’s dependence on sensitive foreign sources. The consortium’s team is comprised of national laboratories, universities, and industrial partners.

Rare earth elements are the most prominent of the critical materials today. CMI aims to develop economically viable processing techniques for improved availability of critical materials for clean-energy technologies, develop new techniques to recover them from waste and scrap, and find acceptable alternatives for use in devices such as generators, motors, lighting, and magnets.

Based on early stage foundational research, CMI has filed 33 U.S. patent applications and 62 records of invention that address rare earth separations for primary metal refining or recycling processes and new magnet compositions and processes. For example, CMI has discovered suitable green and red lamp phosphor substitutes, reducing the use of the rare earth terbium by 90% and eliminating the use of the rare earth lanthanum for green phosphors, and eliminating the use of rare earths europium and ytterbium in red phosphors. Industry is currently assessing the feasibility for commercial lighting via full manufacturing trials.

Additive Manufacturing

There is also tremendous opportunity for U.S. leadership through advances in additive manufacturing or 3D printing of metals, which builds components from the bottom-up by selectively depositing melted metals layer-by-layer. Intense industry interest is focused on additive manufacturing of metal alloys based on a host of potential benefits and applications, including design development, prototyping, customization, and reduction of production waste and costs.

Because of these benefits over traditional manufacturing methods, additive manufacturing processes promise to initiate a renaissance in American manufacturing. Based upon these potential widespread impacts, some expect the economic output of the additive manufacturing industries to be at least $3.1B in 2016 and $5.2B in 2020.

However, a growing consensus within the additive manufacturing community has identified challenges: a lack of fundamental understanding and control of additive manufacturing processes and high quality metal powders necessary to produce the desired properties needed for robust metallic parts. A collaboration between SLAC, Lawrence Livermore National Laboratory, and

Ames Laboratory seeks to provide this important foundational knowledge in manufacturing process control. To overcome the powder-based challenges, Ames Laboratory has established a Powder Synthesis and Development Facility to form a strong partnership with the research community affiliated with the Manufacturing Demonstration Facility at Oak Ridge National Laboratory. This early stage work complements current investments being made by industry, the government, and academic institutions, and the broad return on the investment into this research will be significant.

Summary and Conclusions

The biggest challenge facing U.S. materials research right now is maintaining its global competitive edge. The rest of the world is catching up. Countries like China, South Korea, and India are investing increasing percentages of their GDP in materials research and our competitive advantage in this key enabling science is under threat. Will the U.S. be the first to invent the next catalyst in a $30B petrochemical industry, discover the material that will replace traditional semiconductors in a $350B electronics industry, or provide domestic options for the next critical material on which our military systems depend? The private sector cannot do this by itself. Federally funded research enables world-class materials research, like the ability to address critical material shortages through the basic research provided by the Critical Materials Institute, and the ability to design and create new materials to revolutionize the electronics, lighting, and refrigeration and air conditioning industries, among many other manufacturing sectors. With the current focus on manufacturing and energy to the nation, now is the time to grow and leverage materials research.

Ames Laboratory, like other national laboratories and research universities, is on the cusp of great materials discoveries that will further the nation's economic, energy, and national security interests, but we need your continued support and resources to meet our mission.

Thank you for the opportunity to testify today and again, thank you for your consistent support of materials research. This committee's leadership has paved the way for remarkable innovations. I would be happy to address any questions or provide additional information.