DEPARTMENT OF ENERGY OVERSIGHT: ENERGY INNOVATION HUBS

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTEENTH CONGRESS

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CONTENTS

June 17, 2015

DEPARTMENT OF ENERGY OVERSIGHT: ENERGY INNOVATION HUBS

WEDNESDAY, JUNE 17, 2015

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:37 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Randy Weber [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

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RANKING MEMBER

Congress of the United States
House of Representatives

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Subcommittee on Energy

Department of Energy Oversight: Energy Innovation Hubs

Wednesday, June 17, 2015
10:30 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

Witnesses

Dr. Harry A. Atwater, Director, Joint Center for Artificial Photosynthesis (JCAP)

Dr. Jess Gehin, Director, Consortium for Advanced Simulation of Light Water Reactors (CASL)

Dr. George Crabtree, Director, Joint Center for Energy Storage Research (JCESR)

Dr. Alex King, Director, Critical Materials Institute (CMI)

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

Department of Energy Oversight: Energy Innovation Hubs

Wednesday, June 17, 2015
10:30 a.m. – 12:00 p.m.
2318 Rayburn House Office Building

PURPOSE

The Subcommittee on Energy will hold a hearing titled *Department of Energy Oversight: Energy Innovation Hubs* on Wednesday, June 17, 2015, starting at 10:30 a.m. in Room 2318 of the Rayburn House Office Building. The purpose of this subcommittee hearing is to conduct oversight for the Department of Energy's (DOE) Energy Innovation Hubs. This hearing will focus on evaluating the integrated research approach employed in the four existing hubs, and the impact the hubs have had in their targeted research fields and on existing programs in the Office of Science and the DOE applied energy programs.

WITNESS LIST

- **Dr. Harry A. Atwater**, *Director*, Joint Center for Artificial Photosynthesis (JCAP)
- **Dr. Jess Gehin**, *Director*, Consortium for Advanced Simulation of Light Water Reactors (CASL)
- **Dr. George Crabtree**, *Director*, Joint Center for Energy Storage Research (JCESR)
- **Dr. Alex King**, *Director*, Critical Materials Institute (CMI)

BACKGROUND

The DOE Energy Innovation Hubs were established in 2010, following the management model of collaborative research conducted in the Manhattan Project and AT&T Bell Laboratories.[1] The hubs are integrated research centers that combine basic and applied research with engineering to accelerate scientific discovery and technology development in key energy fields.

The America COMPETES Reauthorization Act of 2015 (as amended) authorized the DOE's four existing Energy Innovation Hubs, which include the Joint Center for Artificial Photosynthesis (JCAP), the Consortium for Advanced Simulation of Light Water Reactors (CASL), the Joint Center for Energy Storage Research (JCESR), and the Critical Materials Institute (CMI). Funds were authorized at approximately $25 million per year per hub. These integrated research platforms are hosted by national labs or universities, and connect multidisciplinary teams of researchers to meet scientific challenges in the areas of (1) artificial photosynthesis to create synthetic fuels; (2) the simulation of reactors through supercomputing to enhance safety and

[1] Department of Energy, Available at http://energy.gov/science-innovation/innovation/hubs

improve performance; (3) to improve battery technology performance; and (4) to enhance recovery and utilization of critical materials.[2]

The Department first established the innovation hub model in 2010 with the Consortium for Advanced Simulation of Light Water Reactors (CASL). CASL is funded through the Department of Energy's Office of Nuclear Energy at approximately $25 million per year. This Hub coordinates among academia, industry, and the national labs to develop a virtual environment for reactor applications (VERA).[3] This set of tools uses DOE super computers to take modeling and simulation capabilities to address CASL's primary technical challenges: (1) enabling power uprates;[4] increasing fuel burn-up and cycle length;[5] and lifetime extensions for U.S. nuclear plants.[6] CASL engages with the Nuclear Regulatory Commission (NRC) on a regular basis to keep the Commission informed of CASL activities and progress.

Funded through the Office of Energy Efficiency and Renewable Energy, the Critical Materials Institute was established in 2011 at Ames National Laboratory to address domestic shortages of rare earth metals and other materials critical for American energy security. Goals for this hub include: diversifying and expanding production of critical materials by designing separation agents to improve production efficiency, reduce costs, and minimize the environmental impact of rare-earth mines; developing transformative and environmentally benign technologies that allow for domestic manufacturing of rare-earth metals, alloys, and other products; and designing chemical extractants that allow for the recovery of lithium from highly concentrated brines.[7] CMI also conducts research into increasing energy efficiency by reducing waste and research designed to create substitute materials to replace existing rare-earth uses.

The Office of Science sponsors two hubs which focus on basic research for energy produced from sunlight and advancing battery storage. The Joint Center for Artificial Photosynthesis (JCAP), led by the California Institute of Technology and funded at $15 million per year, conducts basic research with the goal of designing efficient energy conversion technology that can generate fuels directly from sunlight, water, and carbon dioxide. JCAP projects that it will produce full-system hydrogen-generating solar-fuels prototypes by the end of 2015.[8] During its second phase, JCAP will focus on artificial photosynthetic systems that produce carbon-based fuels by consuming CO_2.

The Joint Center for Energy Storage Research (JCESR) hub, led by Argonne National Lab, develops new battery storage technology through mission-driven basic research, engineering,

[2] Department of Energy, Available at http://energy.gov/science-innovation/innovation/hubs
[3] Consortium for Advanced Simulation of Light-Water Reactors, Available at http://www.casl.gov/mission.shtml
[4] Nuclear Regulatory Commission, defining "power uprate" as "the process of increasing the maximum power level at which a commercial nuclear power plant may operate," Available at http://www.nrc.gov/reactors/operating/licensing/power-uprates.html
[5] Nuclear Regulatory Commission, Available at http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bg-high-burnup-spent-fuel.html
[6] Nuclear Regulatory Commission, "The Atomic Energy Act and NRC regulations limit commercial power reactor licenses to an initial 40 years but also permit such licenses to be renewed," Available at http://www.nrc.gov/reactors/operating/licensing/renewal/overview.html
[7] Critical Materials Institute, Available at https://cmi.ameslab.gov/what-CMI-does
[8] Joint Center for Artificial Photosynthesis, Available at http://solarfuelshub.org/downloads/2015%20JCAP%20Brochure.pdf

technology development, entrepreneurial experience, and commercialization work conducted in collaboration between the lab and private sector and university partners. JCESR research includes: addressing the efficacy of materials architectures and structure in energy storage; charge transfer and transport; and development/utilization of novel computational and measurement techniques.[9] JCESR's current five-year research goals include surpassing lithium-ion systems to provide five times the energy storage at one-fifth the cost within five years.

While DOE Energy Innovation Hubs have existed since 2010, the hubs program has not been authorized by Congress, despite Congressional appropriations of approximately $25 million per year for CMI, JCESR, and CASL, and $15 million per year for JCAP. In FY 2015 appropriations, two Energy Innovation Hubs were renewed for another five-year term, while funds were provided to support continued operations at the other two existing hubs. This hearing will provide additional Congressional oversight for the hubs program.

Important questions and key issues to be discussed at the hearing include:

- What are the primary research and development goals of the four hubs? In the time since each hub was organized by DOE, what progress has been made towards achieving those goals?

- How does the integrated research model employed at the hubs advance research goals within the Office of Science and applied energy programs at DOE?

- How does the private sector interact with each hub? In what way do the hubs prioritize technology transfer of technologies developed at the hub?

[9] Joint Center for Energy Storage Research, Available at http://www.jcesr.org/research/

Chairman WEBER. Good morning, and welcome to today's Energy Subcommittee hearing on the Department of Energy's (DOE) Energy Innovation Hubs.

This hearing will establish Congressional oversight over the four existing Hubs, examining the costs and benefits of the Department's approach to collaborative research and development.

DOE Energy Innovation Hubs are designed to coordinate research efforts across the Department, encouraging cooperation between researchers in basic science, applied energy, and engineering, and bringing together researchers from the national labs, academia, and industry into teams focused on solving critical energy challenges. With appropriate goals, benchmarks, and oversight, this kind of collaborative research and development is just plain old common sense.

Through the national labs, the federal government has the expertise to conduct basic and applied research, while the private sector has the ability and the motivation to move the next-generation energy technology into the marketplace. The Department funds the four Energy Innovation Hubs at approximately $90 million per year. The existing Hubs are focused on a number of energy challenges including extending the life of nuclear power reactors, developing better and more powerful batteries, creating new materials for advanced energy technology, and mimicking the ability that plants have to create fuels from sunlight.

The Consortium for Advanced Simulation of Light Water Reactors, also known as CASL, brings together our best and brightest from industry, academia, and the labs to develop codes to model and simulate operations of the U.S. reactor fleet. These cutting-edge tools allow us to increase our return on investment from DOE's supercomputers within the Office of Science's Advanced Scientific Computing Research program—the subject of a hearing we held in the Energy Subcommittee earlier this year.

One critical application of CASL's virtual environment for reactor applications, known as VERA for short, is to enable the nuclear industry and regulators to predict the performance of reactor components for license renewals by the Nuclear Regulatory Commission (NRC). I'd like everyone to take note of the slide on the screen, which shows what is at stake—it's called The Clock is Ticking—shows what is at stake for the nation's base load electricity from nuclear power if the operating fleet is unable to secure license renewals to 60 years and 80 years of operating life, respectively, and it shows it there on either one of our slides. These NRC license renewals are an important issue for the reliability of our nation's electricity and for my district on The Texas Gulf Coast.

The South Texas Project, currently operating near my district which I used to represent, by the way, as you gentlemen know, provides reliable, zero-emissions electricity to the State of Texas, and good-paying jobs for my constituents. It's pretty clear from this graph just how important these licenses are to maintaining reliable, affordable power across the country. I know that Dr. Gehin has provided a similar figure in his prepared testimony, so I look forward to discussing this important issue today.

The research and development underway in the CASL Hub is just one example of the benefits from this collaborative research approach. The technical expertise and scientific facilities in our national labs can provide tremendous impact on the private sector through appropriate partnerships.

However, while the current DOE Hubs program pursues worthy research goals, not all collaborative research is a guaranteed success. In the first round of Hubs in the program, DOE established a Hub focused on building efficiency. But due to cost, poor performance, and a lack of clear goals, this Hub was dissolved.

Establishing a new Hub, center, or project is not the answer to every problem, and new proposals must be appropriately justified to Congress and shown to meet the research and development goals for the lead DOE office. Any authorization of new or continuing Hubs proposed by DOE must also include the ability to efficiently close down projects that are not achieving clear measures of success.

I want to thank our witnesses today for testifying on their valuable research and the DOE Energy Innovation Hub program. I look forward to a discussion about Federal Government's role in leading collaborative research and development, and how to leverage limited taxpayer dollars for the greatest economic impact and scientific achievement.

[The prepared statement of Chairman Weber follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON ENERGY
CHAIRMAN RANDY K. WEBER

Good morning and welcome to today's Energy Subcommittee hearing on the Department of Energy's (DOE) Energy Innovation Hubs. This hearing will establish Congressional oversight over the four existing Energy Innovation Hubs, examining the costs and benefits of the Department's approach to collaborative research and development.

DOE Energy Innovation Hubs are designed to coordinate research efforts across the Department, encouraging cooperation between researchers in basic science, applied energy, and engineering, and bring together researchers from the national labs, academia, and industry into teams focused on solving critical energy challenges.

With appropriate goals, benchmarks, and oversight, this kind of collaborative research and development is just common sense. Through the national labs, the federal government has the expertise to conduct basic and applied research, while the private sector has the ability and motivation to move the next generation energy technology into the market place.

The Department funds the four energy innovation hubs at approximately $90 million per year. The existing hubs are focused on a number of energy challenges—including extending the life of nuclear power reactors, developing better and more powerful batteries, creating new materials for advanced energy technology, and mimicking the ability that plants have to create fuels from sunlight.

The Consortium for Advanced Simulation of Light Water Reactors, also known as "CASL" [Castle] brings together our best and brightest from industry, academia, and the labs to develop codes to model and simulate operations of the U.S. reactor fleet. These cutting edge tools allow us to increase our return on investment from DOE's supercomputers within the Office of Science's Advanced Scientific Computing Research program—the subject of a hearing we held in the Energy Subcommittee earlier this year.

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I want to thank our witnesses today for testifying on their valuable research, and the DOE Energy Innovation hub program. I look forward to a discussion about federal government's role in leading collaborative research and development, and how to leverage limited taxpayer dollars for the greatest economic impact and scientific achievement.

Chairman WEBER. So, I'm going to recognize the Ranking Member, Mr. Grayson, for an opening statement. He's chomping at the bit.

Mr. GRAYSON. Thank you, Chairman Weber, for holding this hearing, and thank you to our witnesses for joining us today.

I am pleased to see that we have the Director of each Energy Innovation Hub here this morning. These Hubs seek to accelerate scientific discoveries that address critical energy issues, particularly barriers to advancing new energy technology.

Today's hearing is well-timed. Two of the four existing Innovation Hubs are up for renewal this year, while the others are just beginning. The Energy Innovation Hub Program was established only five years ago and this hearing will provide Members an important opportunity to understand further what must be done to ensure the successes of existing, and future, Hubs.

Unfortunately, Congress has yet to provide any authorizing legislation for the important work being performed at each of the Hubs. I hope that today's hearing will provide the insights needed to accomplish that goal. Toward that end, I have already introduced H.R. 1870, a bill that would establish merit-based rules governing the selection, scope, and composition of future Hubs. Further, the Committee hasaccepted the legislative language from that bill as an amendment to the America COMPETES Reauthorization Act, which was considered on the House Floor less than a month ago. I appreciate the Chairman and his staff's efforts to work together to ensure that this important provision was included in the final bill. I also want to thank Ranking Member Johnson for including it in the alternative COMPETES legislation, produced by the Minority, that was offered as a substitute amendment both in Committee and on the Floor.

I am very excited about the possibility of our Committee finally producing authorizing legislation for Energy Innovation Hubs. There are some issues I look forward to learning about this morning, particularly issues regarding Hub management and length of operation. We need develop a plan for Hubs that reach the end of their second five-year contract. Presently, the Department is indicating that Hubs will conclude work after a maximum of ten years only. I support this guidance in principle because it fosters a sense of urgency within Hubs to define and achieve goals as expeditiously as possible.

But what happens when a Hub has been extraordinarily successful? Maybe there should be some process through which, according to merit-based review, that Hub is permitted to continue pursuing promising research and maybe even profound new discoveries.

The answers to these questions, and others, are what I'm looking forward to hearing from you all today. I also look forward to hearing each of your views as to how your own Hub works in the context of Department of Energy research activities and goals across the board. How, specifically, is the research you are performing contributing to the larger effort to solve our nation's pressing energy challenges and needs?

Each of you is involved in exciting and innovative work. I look forward to hearing from you, and watching each of your Hubs as they progress. It's my hope that Congress can provide to you the resources that you need to accomplish your goals, and I look forward to working with you, Chairman Weber, toward that end.

Thank you. I yield the balance of my time.

[The prepared statement of Mr. Grayson follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON ENERGY
MINORITY RANKING MEMBER ALAN GRAYSON

Thank you, Chairman Weber, for holding this hearing, and thank you to our witnesses for testifying today.

I am pleased to see we have the Director from each Energy Innovation Hub here this morning. These Hubs seek to accelerate scientific discoveries that address critical energy issues—particularly, barriers to advancing new energy technologies.

Today's hearing is well-timed. Two of the four existing Energy Innovation Hubs are up for renewal this year, while the others are just beginning. The Energy Innovation Hub Program was established only five years ago, so this hearing will provide Members an important opportunity to further understand what must be done to ensure the successes of existing, and future, Hubs.

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While I am very excited about the possibility of our committee finally producing authorizing legislation for Energy Innovation Hubs, there are some issues I look forward to learning more about this morning. Particularly, issues regarding Hub management and length-of operation.

It is my belief that we must develop a plan for Hubs that reach the end of their second five-year contract. Presently, the Department is indicating that Hubs will conclude work after a maximum of ten years. I support this guidance in principle, because it fosters a sense of urgency within Hubs to define and achieve goals as expeditiously as possible. But what happens when a Hub has been extraordinarily successful? Shouldn't there be some process through which, according to a merit-based review system, that Hub is permitted to continue pursuing promising research?

Furthermore, how can the Department best make sure that the utility of a Hub has been exhausted, and that it is not on the precipice of profound new discoveries?

The answers to these questions, and others, are what I look forward to learning today. I also look forward to hearing each of your views as to how you view your own Hub in the context of larger Department of Energy research activities and goals. How, specifically, is the research you are performing contributing to the larger effort to solve some of our nation's most pressing energy challenges?

Each of you is involved in exciting and innovative work. I look forward to hearing from you, and watching each of your Hubs as they progress. It is my hope that this Congress can provide the resources you need to accomplish your goals, and I look forward to working with you, Chairman Weber, toward that end.

Thank you. I yield the balance of my time.

Chairman WEBER. I thank the gentleman.

Let me introduce our witnesses. Our first witness today is Dr. Harry Atwater, Director of the Joint Center for Artificial Photosynthesis, or JCAP. In addition to his position at JCAP, Dr. Atwater serves as the Howard Hughes Professor of Applied Physics and Material Science at the California Institute of Technology. He specializes in photovoltaics and solar energy as well as plasmonics and optical materials. Dr. Atwater received his bachelor's degree, master's degree, and Ph.D. in electrical engineering from the Massachusetts Institute of Technology.

Our next witness—and welcome, by the way, Dr. Atwater.

Our next witness is Dr. Jess Gehin, Director of the Consortium for Advanced Simulation of Light Water Reactors, or CASL. Dr. Gehin has been with the Oak Ridge National Laboratory for over 20 years. Prior to his current position, Dr. Gehin was a senior R&D staff member performing research primarily in the area of nuclear reactor physics. Dr. Gehin received his bachelor's degree in nuclear engineering from Kansas State University, and his master's degree and Ph.D. in nuclear engineering from MIT. And by the way, welcome, Dr. Gehin.

And I will now yield to the gentleman from Illinois, Mr. Lipinski, to introduce our next witness.

Mr. LIPINSKI. Thank you, Chairman Weber, and thank you, Chairman and Ranking Member Grayson, for holding this hearing.

It's my honor to introduce Dr. George Crabtree, who's the Director of Joint Center for Energy Storage Research, or JCESR, at Argonne National Lab, which is in my district. He's also a distinguished Professor of Physics, Electrical and Mechanical Engineering at the University of Illinois at Chicago, serving as a bridge between Argonne and academia. He has won numerous awards for his research including the Kammerlingh Onnes Prize for his work on vortices and high-temperature superconductors. This prestigious prize is awarded once every three years. Dr. Crabtree is the second recipient. He has won the U.S. Department of Energy's Award for Outstanding Scientific Accomplishment in Solid State Physics four times, which is a very notable accomplishment.

Dr. Crabtree has served as Director of the Material Science Division at Argonne. He has published more than 400 papers in leading scientific journals, has collected over 16,000 career citations, has given over 100 invited talks at national and international scientific conferences. His research interests include next-generation battery materials, sustainable energy, energy policy, material science, nanoscale superconductors and magnets, and highly correlated electrons and medals. Dr. Crabtree co-chaired the Under Secretary of Energy's Assessment of DOE's Applied Energy programs.

I want to thank Dr. Crabtree for joining us today and I look forward to your testimony.

Chairman WEBER. I thank the gentleman. Welcome, Dr. Crabtree. Did he say 16,000 citations? I don't know how you can afford that. Every time I get a citation, my insurance goes up. Yours has got to be astronomical.

Our final witness is Dr. Alex King, Director of the Critical Minerals Institute (CMI). Before joining CMI, Dr. King served as the Director of the Ames Laboratory. Dr. King received his bachelor's degree in physical metallurgy from the University of Sheffield and his Ph.D. in metallurgy and science materials from the University of Oxford. Welcome, Dr. King.

At this time I'm going to now recognize Dr. Atwater for five minutes to present his testimony. Dr. Atwater.

TESTIMONY OF DR. HARRY A. ATWATER, DIRECTOR, JOINT CENTER FOR ARTIFICIAL PHOTOSYNTHESIS (JCAP)

Dr. ATWATER. Okay. Mr. Chairman, distinguished Members, ladies and gentlemen. It's my pleasure to be here today to tell you about the work, the mission and the progress the Joint Center for Artificial Photosynthesis.

So I think it's fair to say that having a source of renewable fuels would be a great source of energy security, economic well-being, and environmental protection for the United States, and JCAP, which is a partnership that's led by Cal Tech, but also with major partnerships with the national labs, Lawrence Berkeley National Labs and Stanford Linear Accelerator Lab, as well as the University of California, is focusing on building the scientific foundation for renewable synthesis of transportation fuels directly from sunlight, water and carbon dioxide using a process called artificial photosynthesis, or otherwise known as generating fuels from sunlight.

So most people are familiar with the idea of generating electricity from sunlight with solar panels that you might put on your roof, so what JCAP is working on is the science behind taking those charge carriers and directly converting those charge carriers that come out of your solar panel into chemical fuels, examples of which are hydrogen, which is generated by splitting water into hydrogen and oxygen, and generating renewable carbon-based fuels by reduction of carbon dioxide. And JCAP was established in 2010, and during its first five years had a primary emphasis on hydrogen production, and its missionary objective, a sort of overarching missionary objective during that time was to develop a robust solar fuel generator for hydrogen generation that operates 10 times more efficiently than natural systems like plants and crops. And I'm happy to say that JCAP has been able to meet that objective of developing a robust solar fuels generator, and more importantly, really developing the concept of what a solar fuels generator is. That's been an important contribution to the scientific field and to the advancement of technology.

In its next five years in renewal, JCAP is going to focus on the— as a main objective, reduction of CO_2 and converting reduction of CO_2 to transportation fuels, direct transportation fuels, and this is really also in addition to a strategic objective for making fuels, it is really a dramatic scientific grand challenge, the reduction of CO_2 selectively, producing exactly one product and not a bunch of by-products is a true scientific grand challenge.

So to date, we have, as I indicated, been able to develop solar fuels generators that operate 10 times more efficiently than plants, and that has really set the stage for a follow-on generation of applied R&D that can develop the scalable generators, and as you may know, there is no existing solar fuels industry. While there's a solar panel industry, there is no solar fuels industry, so it is these innovations that will really set the stage for U.S. industry, a new U.S. industry in this area.

And in the course of its work in generating solar fuels generators, JCAP also discovered new catalysts for water oxidation and reduction, importantly, a method to protect semiconductors against corrosion so they can be long-lasting and robust in their operation.

In addition to these scientific discoveries, JCAP established a number of important facilities including two state-of-the-art labs, one at California Institute of Technology and once at Lawrence Berkeley Laboratory that are purpose-built for solar fuels research. It established new methods for rapid high-throughput screening of materials so we can do experiments that used to take years in matters of weeks. We developed the first facility for so-called benchmarking, or developing standard test conditions for evaluating catalysts so that we can understand how different solar fuels materials operator and perform. We developed new methods for characterization of solar fuels materials using advanced X-ray light source techniques at the Advanced Light Source at Lawrence Berkeley labs and Stanford Linear Accelerator Lab.

Also, to set the stage for a new solar fuels industry, JCAP has been very active in developing invention disclosures, a total of 36 invention disclosures, and 26 patent applications, which are available for licensing to industry, and has an output of scientific results, 200 papers, 60 percent of which are in high-impact journals and numerous key note and invited presentations by research scientists at JCAP.

And so just to highlight some of the things that, you know, why is it that a Hub is an appropriate mechanism to carry on and accelerate this kind of research, JCAP has been able to leverage the integrated Hub concept to make significant advances, one of which I cited earlier, which is the notion that we could accelerate the development of catalyst materials on a time scale that normally takes years in the sort of conventional pace of progress in science, and carry out that in a matter of weeks, and so as an example, in 2013, JCAP developed by a collaboration between two of the JCAP projects, the high throughput experiment project and the heterogeneous catalysis project, new catalyst materials composed of four elements, and there are many, many ways you can combine four elements together in different compositions, so a very large number of samples were made and rapidly screened using high-throughput combinatorial synthesis techniques that allowed us to very rapidly identify candidates and promising candidates were scaled up and tested at the laboratory level, really accelerating that pace of progress.

Another example is the development of a cross-cutting what we call process materials and integration team, a group of applied and basic research scientists that came together from across JCAP to really understand how to put together and design and build very rapidly solar fuels generator prototypes so we could understand what works and what doesn't on a rapid time scale.

So those are many of the key accomplishments, and so for the future, JCAP is going to focus on the grand challenge of—scientific grand challenge of reduction of carbon dioxide in generation of liquid fuels directly from the products, reduced products. This is an area that takes JCAP, which has a translational mission, sort of more upstream in the basic research end, because in the area of carbon dioxide reduction, there are many more scientific challenges and unanswered questions than I think currently exist for the case of hydrogen production. And so it's the opportunity to really unlock the mechanisms and the scientific discoveries that could selectively reduce CO_2 to fuel products that could generate a new generation of generators for liquid fuels, and that's going to be our missionary objective as a scientific grand challenge and setting the stage for a new type of solar fuel generator.

[The prepared statement of Dr. Atwater follows:]

JCAP
JOINT CENTER FOR
ARTIFICIAL PHOTOSYNTHESIS

Congressional Testimony

Committee on Science, Space, and Technology
Subcommittee on Energy
U.S. House of Representatives

June 17th, 2015

Harry A. Atwater, JCAP Director

SUMMARY

The Joint Center for Artificial Photosynthesis (JCAP) —one of four Department of Energy Innovation Hubs— is building the scientific foundation for a scalable solar-powered technology that converts sunlight, water and carbon dioxide into renewable transportation fuels without added energy, in essence making fuels from sunlight. The development of a renewable fuel source that can meet the nation's energy demand is important to the energy security, environmental protection, and economic well being of the United States. In the first 5 years, JCAP helped design the first robust, stable solar-fuel generators for renewable hydrogen production from water splitting—ten time more efficient than in natural systems. The next five years will be focused on converting carbon dioxide into a transportation fuel.

Like natural photosynthesis, artificial photosynthesis uses light-harvesting structures and catalysts to convert sunlight directly into chemical fuels. JCAP's approach uses designs that incorporate scalable, robust non-biological components and materials, some of which are similar to those used in solar photovoltaic panels.

Established on September 30th, 2010, and renewed by the Department of Energy on September 30th, 2015, for another 5 year term, JCAP is led by the California Institute of Technology and its lead partner, Lawrence Berkeley National Laboratory (LBNL), and draws on the expertise of key partners from the Stanford Linear Accelerator (SLAC), and the University of California campuses at Irvine (UCI), and San Diego (UCSD). The leadership team of Director and Senior/key personnel actively manages the research project as a single integrated organization with primary scientific staff and facilities at Caltech and LBNL

JCAP aims to find a cost-effective method to produce fuels using only sunlight, water, and carbon dioxide as inputs. JCAP's mission is the development of manufacturable solar-fuels generators that robustly produce fuel from the sun, ten times more efficiently than current plants and crops. Achieving this goal requires a Hub-scale program, since scientific discoveries are required in many different fields, including electrochemistry, catalysis, semiconductor science

and polymer physics, and JCAP's integrated Hub effort is designed to overcome basic research challenges in harvesting energy from sunlight and catalytic conversion to chemical fuels. The Fuels from Sunlight Hub is unique since there is no established solar fuels industry. Thus JCAP's scientific discoveries and technology advances are designed to enable future commercial development of solar fuels generators and a future artificial photosynthesis industry.

The scope JCAP's artificial photosynthesis program includes two broad solar fuel objectives: i) production of hydrogen from sunlight and water and ii) synthesis of renewable carbon-based transportation fuels from directly from sunlight, carbon dioxide and water.

In its first five years of operation, JCAP's major research emphasis was on hydrogen production, and several important outcomes were achieved. First, scalable designs for solar fuels generators were conceived, prototyped and tested. Second, new multicomponent earth-abundant catalyst materials were discovered and benchmarked. Third, JCAP prototypes have achieved solar fuel generation with efficiency ten times greater than natural photosynthesis. Fourth, outcomes of JCAP's basic research have pointed the directions for future applied research and development on solar fuels generators.

In its renewal program beginning in 2015, JCAP aims to accelerate progress in synthesis of renewable carbon-based transportation fuels. This goal requires discovery of new materials and basic chemical mechanisms for robust solar-driven carbon dioxide reduction under mild conditions, with efficiency exceeding that of natural photosynthesis, and with comparable selectivity. JCAP renewal is focused on design of catalysts for carbon dioxide reduction whose performance is precisely tuned by control of structure, composition and catalytic environment to generate a desired fuel product or precursor. JCAP will develop foundational prototypes, and will integrate its advances with those made by the broader scientific community to lay the foundation for transportation fuels from carbon dioxide.

JCAP's renewal is an actively managed, milestone-driven program, working from an integrated project plan, that seeks to discover new catalytic mechanisms, materials and components, and evaluate their performance as elements of a solar fuels generator:

a. *Mechanisms*: JCAP researchers are significantly expanding the discovery of scientific concepts and understanding for heterogeneous CO_2 reduction and oxygen evolution catalysis, under both dark and sunlight-illumination conditions, yielding catalysts that are active, stable, and selective to give products such as hydrocarbons and alcohols.

b. *Materials*: Discovery of new materials is being accelerated by use of high-throughput experimentation, a powerful materials discovery capability that automates the synthesis and hierarchical screening of new light harvesting and catalyst materials for solar-fuels generation. These high-speed, combinatorial experimental techniques are paired with new theoretical methods for rapid combinatorial analysis and screening to build a comprehensive database of promising candidate materials, whose performance will be assessed and improved through directed materials research.

c. *Components*: By combining catalysts, light absorber materials, electrolytes, membranes and protective coatings, JCAP is working to realize photocathodes and photoanodes for carbon dioxide reduction and oxygen evolution and evaluate their performance under model and real-world conditions. These components will form the candidate building blocks for a solar-driven solar fuels generator prototype capable of producing carbon-based transportation fuels and form the scientific and technical foundation for a new sustainable fuels technology.

What are the primary research and development goals of JCAP? Since the hub was organized by DOE, what progress has been made towards these goals?

Established on on September 30th, 2010, the primary research and development goal for the Joint Center for Artificial Photosynthesis (JCAP) over the last five years has been to realize a scalable solar fuels generator with efficiency at least ten times greater than that for natural photosynthesis. In the last five years, a revolution has occurred in the understanding and development of solar-fuels generators for renewable hydrogen production from water splitting. Since its inception, the Joint Center for Artificial Photosynthesis (JCAP) has played a leading role in this revolution by integrating advances spanning from discovery of catalysts and development of protection coatings for light absorbers, to new system concepts for self-sustaining integrated solar-fuels generators.

Selected Achievements to Date

- JCAP's discoveries and designs for integrated solar-fuels generator prototypes in its first five years have enabled to solar-to-hydrogen efficiency ten times greater than in natural systems.
- This work has set the stage for development of the next generation of integrated water splitting solar-fuels generators with even higher efficiency.
- New earth-abundant catalyst materials for water oxidation and proton reduction were discovered.
- A new method to protect semiconductors from corrosion was discovered, greatly expanding the range of candidate materials usable in solar fuel generators.
- 2 state-of-the-art laboratory buildings, purpose-built for solar fuels research, were commissioned.
- A high-throughput experimentation facility for efficient and rapid preparation, screening, and analysis of light absorbers and catalysts was developed.
- New X-ray measurement techniques were developed, in partnership with LBNL and SLAC, for synthesis and characterization of solar fuels materials.
- A catalyst-benchmarking laboratory was established to serve as a resource to define standard testing conditions for solar fuels catalyst performance.
- JCAP has filed 36 invention disclosures and filed 26 patent applications.
- 200+ archival scientific papers have been published, 60% of which are in high impact factor scientific journals.
- JCAP researchers have made over 200 keynote or invited presentations at scientific conferences and technical meetings.

Over the 2010-2015 period, the project plan for JCAP has been focused largely on hydrogen production. At the same time, the solar-fuels revolution is only partially complete, since creation of an integrated generator of carbon-based fuels from carbon dioxide reduction remains a grand challenge. Basic science advances are needed to understand CO_2 reduction catalysis and enable highly selective formation of fuel products. Beyond catalyst discovery, a critical need is the integration of required knowledge, materials and components to form a solar-fuels generator.

In its renewal phase, which will begin on September 30th, 2015, JCAP will capitalize on its developments in water splitting and turn its primary focus to solar-driven carbon dioxide reduction processes under mild conditions. We will pursue routes with high selectivity and efficiency exceeding that of natural photosynthesis. JCAP's renewal is focused on generation of hydrocarbon or alcohol fuel products whose heating value equals or exceeds that of methanol. This requires accelerated discovery of new catalytic mechanisms and materials and development of robust components suitable for integration into a solar-fuels generator.

The goals of the 5-year renewal project include the following advances in catalytic mechanisms, materials discovery and testbed development:

- Discovery and understanding of highly selective catalytic mechanisms for carbon dioxide reduction and oxygen evolution under mild conditions of temperature and pressure, and with input partial pressures of carbon dioxide in air between ambient atmospheric levels of 400 ppm and 1 atm. These advances will inform the design of overall solar-energy-to-fuels components for key processes including light capture, energy transfer, electron transport and charge separation.
- Discovery of electrocatalytic and photoelectrocatalytic materials and useful light-absorber photoelectrodes. This is required to design and construct components for test-bed prototypes that demonstrate selective, efficient CO_2 reduction into hydrocarbon fuels at full solar flux.
- Demonstration, in JCAP test-bed prototypes, of artificial photosynthetic carbon dioxide reduction components and oxygen evolution components that exceed natural photosynthesis in efficiency and rival it in selectivity. Results of these demonstrations will be used to determine the practicality of prototype solar-fuels systems.

How does the integrated research model employed at the hubs advance research goals within the Office of Science and applied energy programs at DOE?

JCAP is funded through DOE's Office of Science, Basic Energy Sciences, Chemical Sciences Division, a basic energy program, and it is headquartered at the California Institute of Technology, with major partners at Lawrence Berkeley National Laboratory and the Stanford Linear Accelerator Laboratory, in addition to partnerships with the University of California campuses at Irvine and San Diego. By design, the hub is integrated across the spectrum of basic and applied research as necessary to achieve its goals, and has the ability to draw on resources from the Office of Science and its partner institutions. The basic science research advances made by JCAP under its Office of Science project are stimulating new technology directions of interest to the DOE applied energy programs in the Office Energy Efficiency and Renewable Energy.

Our strategy recognizes the need to accelerate discovery in the context of a high-risk, high-reward research and development program, and to go beyond discovery to evaluate solar-fuels generator components. The Hub partners have been selected to address these challenges as an integrated, cohesive team. Because of the high-risk nature of a discovery-oriented program, JCAP management and key scientific leaders act as an empowered, flexible team to rapidly assess progress, failure and success, and to dynamically reallocate resources in response to promising developments. JCAP's project plan supports a balance of accelerated discovery and integration in a framework for project evaluation against technical milestones.

A cross-disciplinary and cross-site R&D effort can only thrive in an environment that fosters seamless communication between scientists and with management, across all institutional partners. From the beginning of JCAP, we configured operations and programs to enable frequent and unhindered communication by: 1) co-locating researchers in JCAP's major laboratory facilities; 2) supporting extensive telepresence/video networking between the sites; 3) incentivizing cross-site visits and cross-site integration teams; 4) organizing regular community-building activities (e.g., weekly research meetings, annual all-hands meetings, seminars, summer schools and short courses.)

The Hub's management structure and communication mechanisms ensure that all members are actively engaged and familiar with JCAP's goals, project plan, timelines and technical progress. Daily, weekly and biweekly meetings are used to present and discuss progress and steps needed to achieve the Hub's research mission. All of the Hub's members review progress against JCAP's Project Plan frequently, using it to set research priorities. JCAP fosters a culture of openness and transparency. For example, research meetings are open to all members of JCAP, and all of the Hub's members use them to provide feedback and to improve their understanding of each other's work. External reviews and self-assessments are disseminated to all members of JCAP so that the status of work and areas for improvement are known and discussed. These regular processes have established strong connections across the Hub that have in turn enabled rapid response times and good teamwork.

There are many examples of JCAP's effectiveness in research integration, one of them culminating in discovery and characterization of a new family of robust metal oxide catalysts for water oxidation. This success was realized in late Spring of 2013 as a result of suggestions to the High Throughput Experimentation project from the Heterogeneous Catalysis project that an investigation of films composed of four elements could yield improved catalysts. The required inks were formulated, the combinatorial plates were made and screened, and compositions from promising regions were scaled up for benchmarking to compare activity quantitatively relative to known catalysts. The compositions were then scaled up yet again for testing in a prototype testbed, synthesized by electrodeposition, and tested. All of these activities occurred over the period of less than twelve weeks. This highly collaborative effort yielded unprecedentedly rapid advances that could only be produced because of JCAP's capabilities and integrated Hub model featuring cross-project teamwork involving researchers at Caltech and Lawrence Berkeley National Laboratory.

To improve and solidify cross-Project integration and collaboration, JCAP added a crosscutting team structure to the Hub in 2013. The teams are complementary to the existing eight projects and serve as a means of directly facilitating cross-project strategy and planning for and execution of, ongoing broad multi-project research. A typical team has members from several projects across JCAP and is led by two early-career staff scientists. Each team is by design a dynamic body, with a set of core members and researchers, who transition in and out of the team depending on the status and type of work being done.

To achieve its aggressive 5-year goals, JCAP leverages the resources and capabilities of other major solar-fuels research programs, of the DOE User Facilities, and of its core industry partners. Working together with key Energy Frontier Research Centers including the Northwestern/Argonne ANSER Center and the UNC Center for Solar Fuels, as well as the Stanford GCEP program, the NSF CCI Solar program, and the Resnick Institute at Caltech, JCAP is actively promoting a robust interactive solar-fuels community in the United States. JCAP will also draw upon state-of-the-art tools of DOE User Facilities including those of the Advanced Light Source at LBNL and Stanford Synchrotron Radiation Laboratory at SLAC for *in situ* and *operando* characterization of catalysis, NERSC (LBNL) for computational theory, modeling, and simulations, and the Molecular Foundry (LBNL) for material synthesis and nanofabrication. JCAP is developing an industrial partnership, and has had interactions with Dow Chemical, Panasonic, Siemens, and Arkema, all of which have existing research programs and long-term

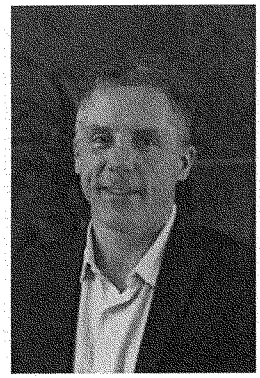
How does the private sector interact with JCAP? In what way does JCAP prioritize technology transfer of technologies developed at the hub?

There is currently no existing solar fuels industry sector, which is due in part to the basic science challenges that need to be addressed before a solar fuels industry can develop. In fact, this is why a Hub-scale effort is critically needed -to accelerate progress more rapidly in this area- than would be possible via other Department of Energy programs.

JCAP's relationship with the private sector is defined by its goal of building --from basic scientific understanding-- the technology components, intellectual property instruments and institutional relationships to foster a robust future solar fuels industry in the United States. Effective communication and potential collaborations between JCAP and industry could result in foundational discoveries (scientific and technical) that can accelerate the development of a solar fuels industry as well as benefit other industrial processes, for instance those reliant on carbon dioxide reduction.

To facilitate technology transfer, JCAP has been very proactive in filing invention disclosures and patent applications. To date, JCAP has filed 36 invention disclosures and filed 26 patent applications.

JCAP has developed an industrial partnership program to coordinate industrial interactions, and is building collaborations with major multinational industry partners, including Dow, Panasonic, Siemens, and Arkema, all of which have existing research programs in CO_2 catalysis, and long-term strategic interest in the development of a solar-fuel technology. JCAP has also received valuable guidance on strategic direction from its Strategic Advisory Board, which includes industry representatives from Dow Chemical, Boeing, Applied Materials, and Proton Onsite Inc.



Harry Atwater is the Howard Hughes Professor of Applied Physics and Materials Science at the California Institute of Technology. Professor Atwater currently serves as Director of the DOE Joint Center for Artificial Photosynthesis. Atwater's scientific interests have two themes: photovoltaics and solar energy as well as plasmonics and optical metamaterials. His group has created new high efficiency solar cell designs, and have developed principles for light management in solar cells. Atwater is an early pioneer in nanophotonics and plasmonics; he gave the name to the field of plasmonics in 2001. He has authored or co-authored more than 400 publications cited in aggregate > 33,000 times and his group's advances in the solar energy and plasmonics field have been reported in Scientific American, Science, Nature Materials, Nature Photonics and Advanced Materials.

He is co-founder and chief technical advisor for Alta Devices, a venture-backed company in Santa Clara, CA, that holds the current world record for 1 Sun single junction solar cell efficiency and that is currently transitioning high efficiency/low cost GaAs photovoltaics technology to manufacturing and large-scale production. He serves as Editor in Chief for the journal ACS Photonics, and is Associate Editor for the IEEE Journal of Photovoltaics, and in 2006 he founded the Gordon Research Conference on Plasmonics, which he served as chair in 2008.

Harry Atwater is a Fellow of the Materials Research Society, and Member of US National Academy of Engineering. Atwater has been honored by awards, including: (2014) Julius Springer Prize in Applied Physics, (2014) ISI Highly Cited Researcher, (2013) Fellowship from the Royal Netherlands Academy of Arts and Sciences, (2012) ENI Prize for Renewable and Non-conventional Energy, SPIE Green Photonics Award (2012), MRS Kavli Lecturer in Nanoscience (2010), the Popular Mechanics Breakthrough Award (2010). He received the Joop Los Fellowship from the Dutch Society for Fundamental Research on Matter (2005), the A.T.&T. Foundation Award (1990). He won the NSF Presidential Young Investigator Award (1989) and the IBM Faculty Development Award in 1989-1990.

Professor Atwater has worked extensively as a consultant for industry and government, and has actively served the materials community, including Material Research Society Meeting Chair in 1997, AVS Electronic Materials and Processing Division Chair in 1999, Materials Research Society President in 2000, and Board of Trustees of the Gordon Research Conferences. He also teaches graduate level Applied Physics classes at Caltech in optoelectronics, solid-state physics and device physics.

Professor Atwater received his B. S., M. S. and Ph.D. degrees from the Massachusetts Institute of Technology respectively in 1981, 1983 and 1987. He held the IBM Postdoctoral Fellowship at Harvard University from 1987-88, and has been a member of the Caltech faculty since 1988.

Web Links:

http://solarfuelshub.org/index.html

http://daedalus.caltech.edu

http://www.lmi.caltech.edu

Chairman WEBER. Thank you, Dr. Atwater.
Dr. Gehin.

TESTIMONY OF DR. JESS GEHIN, DIRECTOR, CONSORTIUM FOR ADVANCED SIMULATION OF LIGHT WATER REACTORS (CASL)

Dr. GEHIN. Thank you very much, Chairman Weber, Ranking Member Grayson, and Members of the Subcommittee. It's my honor to be here to provide this testimony on the Energy Innovation Hub integrated research approach.

CASL was the first Hub established by the Department of Energy in July 2010. It's currently completing its first five-year term. It consists of 10 core founding partner institutions from academia, national laboratories and industries led by Oak Ridge National Laboratory.

Our focus is on innovations in nuclear commercial power generator, specifically the advanced modeling and simulation of nuclear reactors. CASL's vision is to predict with confidence the performance of nuclear reactors through comprehensive science-based modeling and simulation technology that is deployed and applied broadly throughout the nuclear energy industry to enhance safety, reliability and economics. CASL is capitalizing on advancements in computing and is helping retain and strengthen U.S. leadership in two key mission areas of high-performance computing and nuclear energy.

CASL targets R&D in technical areas that have been selected as significant current industry challenges where modeling and simulation can provide meaningful advancements, particularly to help achieve increases in operating power, life extensions and higher fuel utilization. Many of the CASL developments are focused on key phenomena that limit power generation and so they can improve operations. Similarly, a significant benefit can be achieved through further life extensions by ensuring that reactor life-limiting components can meet their design requirements for longer operating periods beyond the current license renewals.

CASL's integrated research model is based on establishing an organization with outstanding researchers with a clear and agile research plan. Let me point out a few of the key features of this integrated model: central integrated management decision making and program integration, strong science and engineering applications and design leadership, independent oversight and review by an external board of directors, science and industry councils for oversight, review and advice, an agile work process based on 6-month planning execution periods.

In order to achieve our research goals, CSL is developing a virtual reactor that we call VERA, which stands for the virtual environment for reactor applications. Our key research accomplishments in the development of VERA include creating a comprehensive Hub environment that supports a large team of researchers working on developing, testing and deploying VERA, the virtual reactor; developing computational methods and computer codes for all key physics needed to model reactor operation; applying VERA to several—to simulate several nuclear power plants including the Watts Bar nuclear plant near Oak Ridge, which is designed by

Westinghouse and operated by TVA, both partners in CASL; and coupling of physics software components and models with initial applications providing integrated simulation capabilities not previously available.

The key metric of the success of CASL's modeling and simulation capabilities is deployment to nuclear industry where these tools can be used. In order to achieve this, we have strong engagement with our industry partners and a broad connection with private industry through the integration of more than 50 additional contributing partners. CASL also relies an industry-led industry council with over 25 members from the broader nuclear energy and modeling simulation industries.

VERA has already been deployed in industry engineering environments through CASL test stands. This includes, for example, the use of VERA at Westinghouse for simulating the AP–1000 reactor to confirm their own engineering calculations. In CASL's second five-year term, VERA will be expanded beyond pressurized water reactors to support boiling water reactors, which represent the remainder of our current operating fleet. We will also consider future light water reactor designs including small modular reactors.

In conclusion, Energy Innovation Hubs represent an effective research model that enables CASL to conduct basic and applied research for critical energy application. Through the Hub model, CASL has tapped into DOE advanced computing strengths and nuclear energy research capabilities. We have taken advantage of the best and brightest university researchers and we have integrated decades of industry experience and expertise. This highly integrated, focused R&D partnership has demonstrated accomplishments at a rapid pace, notably including successful deployments to several industry end users. As the first Energy Innovation Hub, CASL has clearly demonstrated that this research model can be a very effective method to deliver targeted research and rapid solutions to address complex issues.

Thank you very much.

[The prepared statement of Dr. Gehin follows:]

Congressional Testimony

Jess C. Gehin
Director, Consortium for Advanced Simulation of Light Water Reactors
Oak Ridge National Laboratory

Before the
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives

Hearing on Department of Energy (DOE) Innovation Hubs

June 17, 2015

Chairman Weber, Ranking Member Grayson, and Members of the Subcommittee, I am pleased to appear before you today.

My name is Jess Gehin. I am the Director of the Consortium for Advanced Simulation of Light Water Reactors (CASL), a DOE Energy Innovative Hub consisting of 10 core founding partner institutions and lead by Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. It is an honor to provide testimony on the Hub integrated research approach and progress towards of our research and development goals.

Summary

Energy Innovation Hubs bring together teams of top scientists and engineers from academia, industry, and government to collaborate and overcome critical known barriers to achieving national climate and energy goals that have proven resistant to solution via the normal R&D enterprise. Hubs apply a research model inspired by AT&T Bell Labs and the Manhattan Project that resulted in a tremendous number of innovations that helped win the Second World War. More specifically, Hubs focus on a single topic, with the objective of rapidly bridging the gaps between basic research, engineering development, and commercialization through a close partnership with industry. To achieve this goal, the Hubs necessarily consist of large, highly integrated and collaborative creative teams working to solve priority technology challenges.

In July 2010, the Consortium for Advanced Simulation of Light Water Reactors (CASL) was the first Hub established by the Department of Energy. CASL is focused on innovations in commercial nuclear power generation, specifically the modeling and simulation (M&S) of nuclear reactors. CASL's vision is to *predict, with confidence, the performance of nuclear reactors through comprehensive, science-based M&S technology that is deployed and applied broadly throughout the nuclear energy industry to enhance safety, reliability, and economics.* CASL is bringing innovation to the nuclear energy enterprise by helping it capitalize on advancements in computing over the past few decades and is helping retain and strengthen U.S. leadership in two DOE mission areas: high performance computing-enabled M&S and nuclear energy. CASL implements several key Hub management elements: clear deliverables and products that solve industry issues driven by a well-defined yet dynamic plan; a strategy of delivering prototype products early and often; and targeted

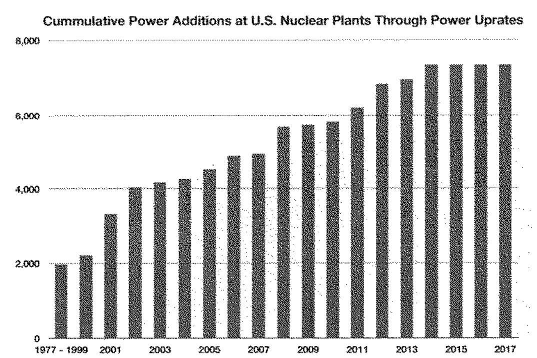
customers and users. CASL is currently completing the fifth year of its first five-year term (Phase 1); in January 2015, DOE approved a second five-year term for CASL (Phase 2).

CASL's R&D supports the U.S. energy mission by targeting technical challenges that have been carefully and collaboratively selected as significant, current industrial challenges where M&S can provide meaningful advancements. This is the CASL "Challenge Problems" approach to addressing phenomena that industry is spending hundreds of millions of dollars to address (through resolution or avoidance). In this approach CASL has identified industry Challenge Problems that can help achieve nuclear reactor power uprates, life extensions, and higher fuel utilization. In order to achieve this, CASL is developing a *virtual reactor* called the Virtual Environment for Reactor Applications (VERA).

Introduction

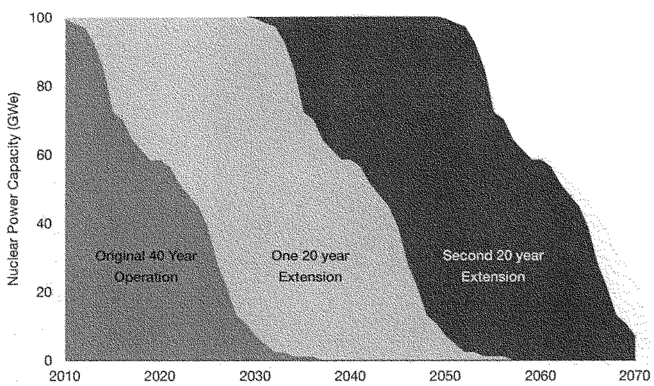
Nuclear power plants are the largest clean-air energy source in the U.S. As the U.S. moves toward a clean-energy economy, nuclear energy must continue to be a part of the energy mix. Yet many challenges remain for nuclear energy—both for the existing U.S. fleet as well as for new reactors; improvements must be made in economics and performance. The future of the commercial nuclear power industry hinges upon furthering power uprates, realizing higher fuel burnup, and operating the existing plants for longer lifetimes—all while providing higher confidence in assured nuclear safety for both the current fleet and the next generation of nuclear power technology.

As illustrated in the figures below, large gains in U.S nuclear energy production can be provided through marginal increases in operation and life extension. The first figure provides the cumulative increases in nuclear power generation achieved through improved operations resulting in the addition of approximately 7,000 MWe, or roughly the equivalent of seven nuclear power plants. CASL's modeling and simulation is focused on physical phenomena that currently limit plant power output; higher fidelity understanding of these phenomena has the potential to facilitate generation of more power using these plants.



Nuclear energy generation additions (in MWe) at U.S. nuclear power plants through power uprates (increases in licensed operating powers) (source of data: U.S. NRC).

Similarly, the next figure illustrates the positive impact resulting from extending the lifetime of the U.S. nuclear power fleet. The originally licensed lifetime was conservatively set at 40 years; through industry and government research, many plants have received approval for an additional 20 years, extending our national investment into clean energy, low-cost nuclear power generation benefits past 2040. The figure also shows a profile that represents the expanded benefit through 2060 resulting from a subsequent 20-year life extension. One part of enabling this is to ensure that reactor life-limiting components can meet their design requirements. For example, the reactor vessel that contains the reactor core is a critical component that cannot be replaced. CASL, working with DOE's Light Water Reactor Sustainability Program, is developing capabilities to understand the performance of reactor vessels for extended plant lifetimes, providing valuable information to support the continued operations of our reactor fleet.



Nuclear energy capacity profiles in United States for original plant 40 year licenses and profiles assuming all existing plants receive a 20 year extension to 60 years and a subsequent 20 year license extension to 80 years (assumes 100 GWe fleet, no additional power uprates or premature plant shutdowns) (source of data: U.S. NRC).

CASL Organization and Management

CASL's unique partnership of universities, DOE national laboratories, and industry possesses unparalleled institutional knowledge, nuclear science and engineering talent, computational science leadership, and LWR design and regulatory accomplishments. The CASL team includes renowned nuclear research universities, extensive expertise and facilities in nuclear sciences and in modeling and simulation at our national laboratories and industry, which provides combined reactor operating experience of thousands of reactor operating cycles, with data and design experience supporting the application and validation of CASL's VERA.

Oak Ridge National Laboratory is CASL's lead institution for CASL, with the following additional Founding Partners:

- Electric Power Research Institute
- Idaho National Laboratory
- Los Alamos National Laboratory
- Massachusetts Institute of Technology
- North Carolina State University
- Sandia National Laboratories
- Tennessee Valley Authority
- University of Michigan
- Westinghouse Electric Company

The Hub approach specifically provides a unique opportunity for researchers, scientists, and engineers from across this broad set of organizations to directly work together more closely than is typical of government research projects.

CASL's integrated research model is based on establishing an organization with the best and brightest researchers with a clear and agile research plan. The primary features of this integrated model are:

- Central, integrated management working predominately from a single location at ORNL: Director with full line authority and accountability for all aspects of CASL; Deputy Director to drive program planning, performance and assessment; Chief Scientist to drive science-based elements; experienced Focus Area Leads and Deputies with responsibility for the core science and engineering elements;
- Strong science, engineering, applications, and design leadership;
- A virtual one-roof approach utilizing widespread implementation of state-of-the-art collaboration technology;
- Well-informed and timely decision-making and program integration;
- Independent oversight and review via an external Board of Directors (BOD) advising on annual performance goals, tactical and strategic plans, and performance metrics and Science and Industry Councils for external oversight, review, and advisory functions;
- Integrated project management across CASL for scope/schedule/budget planning and tracking and an integrated Operations and Management Support team providing clear leadership for environment, safety, and health; partnerships and intellectual Property management; finance and procurement; quality; and security;

CASL's work is identified, constructed, planned, and executed within period durations of six-month known as Plans of Record (PoRs). Planning and working in these six month periods allows managed change that is dynamic and responsive to approved change while still meeting, or exceeding, commitments made at the onset of the PoR. This is consistent with modern agile project management philosophies and has been highly effective.

CASL Research Goals and Progress

To complete its mission and realize its vision, CASL has four strategic goals:

- Address design, operational, and safety challenges for LWRs;
- Develop and effectively apply modern virtual reactor technology;
- Engage the nuclear energy community through modeling and simulation; and
- Deploy new partnership and collaboration paradigms.

In order to achieve these strategic goals, in its first five years (Phase 1), CASL has developed a M&S capability called the Virtual Environment for Reactor Applications (VERA) that integrates simulation capabilities of key physical phenomena in a nuclear reactor core: neutronics, thermal-hydraulics, chemistry, and nuclear fuel performance. VERA provides for a higher fidelity and resolution for modeling the reactor core and vessel systems of a nuclear reactor than is currently available in industry. This capability, combined with modern uncertainty quantification approaches, is focused on helping to address key industry challenges related to pressurized water reactor (PWR) core performance in normal and accident conditions. VERA has been deployed to early adopters through CASL Test Stands, to be discussed in more detail below.

Key CASL's accomplishments and initiatives include:

- A successful, comprehensive Hub development environment has been created and supports a large team of researchers working on developing, testing, and deploying the VERA virtual reactor;
- The computational methods and computer codes representing all of the key physics to be included in VERA (neutronics, fuel performance, fluid flow/heat transfer, and chemistry) have undergone their initial development and have been integrated into the software;
- VERA has been applied to simulate several nuclear power plants, including several operating cycles of the Watts Bar Nuclear Plant where results have been compared with measured plant data and showed a high degree of consistency;
- Coupling of physics software components and models have been performed with initial applications to the corrosion product deposition challenge problems based both on high-resolution localized deposition prediction and detailed three-dimensional core modeling;
- Early deployment of VERA to industry engineering environments has been performed through CASL Test Stands:
    - As part of a Westinghouse Test Stand, the startup of the AP1000® reactor has been simulated in very high detail and used within Westinghouse to confirm their engineering calculations;
    - The Electric Power Research Institute has assessed the use of the VERA for analyzing fuel performance using their industry guidelines;
    - The Tennessee Valley Authority is using VERA to simulate coolant flow within the Watts Bar Unit 1 reactor vessel;
- In Phase 2, CASL is expanding VERA to encompass the design extents of the existing and currently envisioned commercial nuclear fleet by including options for simulation of Boiling

Water Reactors (BWRs) and Small Modular Reactors (SMRs), and through the addition of features supporting simulation of additional operating conditions;

- In Phase 2, CASL is planning for the long-term sustainability of the Hub technology through broad deployment of VERA throughout the industrial and academic communities.

The research performed by CASL is well disseminated throughout the scientific community through technical reports, conference presentations and proceedings, seminars, and peer-reviewed journal publications. To date more than 113 journal articles, 360 conference papers, 118 invited talks, and 500 technical reports have been created documenting our research, many of which are available on the CASL website (www.casl.gov).

Transferring CASL Technology and Knowledge to the Private Sector

A key metric of the success of the development of M&S capabilities is deployment to the end user. While Phase 1 was focused on innovation and on developing capabilities to address Challenge Problems, a sizable effort went into understanding stakeholder requirements, educating future VERA users, and deploying CASL technologies to end users. In Phase 2, CASL is placing heavy focus on deployment and outreach through the addition of a new Technology Deployment and Outreach (TDO) activity. TDO is chartered to ensure the continued flow of CASL technology to the nuclear energy community, with a particular focus on the commercial power industry and U.S. universities. To achieve a wide deployment, TDO will work in four primary areas: long-term sustainability of CASL technology, outreach, test stand deployments, and VERA release and support.

Test Stands serve as a primary mechanism for early deployment of CASL-developed technology to key stakeholders, including the private sector. They also provide direct stakeholder feedback on VERA usability and capability and permit additional demonstrations of CASL-developed capabilities on applications that are not directly addressed as part of the CASL development effort. The first Test Stands were executed with the CASL industry partners (EPRI, TVA, and Westinghouse) that represent a broad spectrum of industry stakeholders; thus, these partners provided an ideal initial environment to demonstrate and evaluate VERA. Additional, external Test Stands (outside the CASL partnership) are being planned. Test Stand hosts generally reported very positive experiences. For example, "Westinghouse reported, "...the results already obtained, and those to come in the future now that the codes have been deployed on the Westinghouse cluster, [are] viewed by Westinghouse as possessing extremely high value." Similarly, the Test Stands with EPRI and TVA have provided highly valuable feedback to guide CASL's research.

In addition to engagement of the Industry Founding partners, CASL has developed a broad connection with private industry through the integration of more than 50 contributing partner organizations that support CASL's research. CASL also relies on an industry-led Industry Council with over 25 members from the nuclear energy and modeling and simulation industries to provide feedback and input to CASL. CASL also engages with the U.S. Nuclear Regulatory Commission (NRC), to inform them on our research. An education program has also been established to ensure that the next generation of engineering graduates with the knowledge needed to use VERA for real-world applications. This includes lectures, course materials, and CASL summer schools.

A CASL Intellectual Property Management Plan (IPMP) has been developed to establish guidelines for making CASL IP available to the US nuclear energy community, while protecting partner IP from inappropriate access and distribution. Non-disclosure agreements were executed that enable open sharing of information within the CASL partnership. Several classes of licenses are currently in use or under development to support distribution of CASL technology. A comprehensive export control review process has also been established to ensure that internal and external discussions about VERA development and release of the VERA software meet all applicable export control regulations.

Conclusion

Energy Innovation Hubs represent an effective research model that CASL has successfully implemented to connect basic and applied research to critical energy applications. Through the Hub model, CASL has efficiently tapped into the DOE's advanced computing strengths and nuclear energy research capabilities, taken advantage of the best and brightest of university researchers, and also been privy to decades of industry experience and expertise. This highly integrated, focused R&D partnership has demonstrated accomplishments at a rapid pace in its first five years, notably including successful deployments to several industry end users. Building on this success, CASL's second phase will expand its applications, achievements, and impact to a broader range of problems and through broader deployment and application. As the first Energy Innovation Hub, CASL has clearly demonstrated that this research model can be a very effective method to deliver targeted research and rapid solutions to address complex issues. Based on this experience, the CASL Hub approach represents a good model to be adopted for future public-private research consortia.

Summary of Congressional Testimony

Jess C. Gehin
Director, Consortium for Advanced Simulation of Light Water Reactors
June 17, 2015

The Consortium for Advanced Simulation of Light Water Reactors (CASL) was the first Hub established by the Department of Energy with a vision to *predict, with confidence, the performance of nuclear reactors through comprehensive, science-based modeling and simulation technology that is deployed and applied broadly throughout the nuclear energy industry to enhance safety, reliability, and economics.* The full testimony addresses the following questions:

1. What are the primary research and development goals of CASL? Since the hub was organized by DOE, what progress has been made towards those goals?

CASL has identified industry Challenge Problems that can help achieve nuclear reactor power uprates, life extensions, and higher fuel utilization. In order to achieve these strategic goals, CASL has developed an advanced modeling and simulation technology called the Virtual Environment for Reactor Applications (VERA) that integrates simulation capabilities of key physical phenomena in a nuclear reactor core. VERA has been rigorously assessed and applied model several nuclear plants including several operating cycles of TVA's Watts Bar Nuclear Plant and through CASL Test Stands deployed to industry.

2. How does the integrated research model employed at the hubs advance research goals within the Office of Science and applied energy programs at DOE?

CASL's unique partnership of universities, DOE national laboratories, and industry possesses unparalleled institutional knowledge, nuclear science and engineering talent, computational science leadership, and LWR design and regulatory accomplishments. CASL's integrated research model is based on establishing an organization with the best and brightest researchers with a clear and agile research plan. CASL is bringing innovation to the nuclear energy enterprise and is helping retain and strengthen U.S. leadership in two DOE mission areas: high performance computing-enabled M&S and nuclear energy. CASL's integrated research model includes clear deliverables and products that solve industry issues as driven by a well-defined yet dynamic plan; a strategy of delivering prototype products early and often; and targeted customers and users.

3. How does the private sector interact with CASL? In what way does CASL prioritize technology transfer of technologies developed at the hub?

CASL includes private sector organizations as part of its research and development activities through its three Industry Founding Partners (Westinghouse Electric Company, Electric Power Research Institute, and TVA). In addition to engagement of the Industry Founding partners, CASL has developed a broad connection with private industry through the integration of more than 50 contributing partner organizations that support CASL's research. CASL also relies on an industry-led Industry Council with over 25 members to provide feedback and input to CASL. In Phase 2, CASL is placing heavy focus on deployment and outreach through the addition of a new Technology Deployment and Outreach (TDO) activity chartered to ensure the continued flow of CASL technology to the nuclear energy community, with a particular focus on the commercial power industry and U.S. universities. To achieve a wide deployment, TDO will work in four primary areas: long-term sustainability of CASL technology, outreach, test stand deployments, and VERA release and support. Technology transfer is prioritized to maximize impact to industry.

Congressional Testimony

Jess C. Gehin
Director, Consortium for Advanced Simulation of Light Water Reactors
Oak Ridge National Laboratory

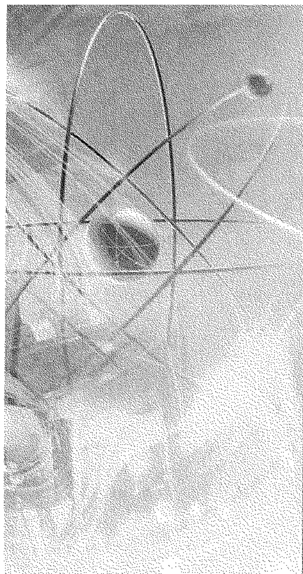
Before the
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives

Hearing on Department of Energy (DOE) Innovation Hubs

June 17, 2015

APPENDIX 1

CASL Brochure



CASL
A DOE Energy Innovation Hub

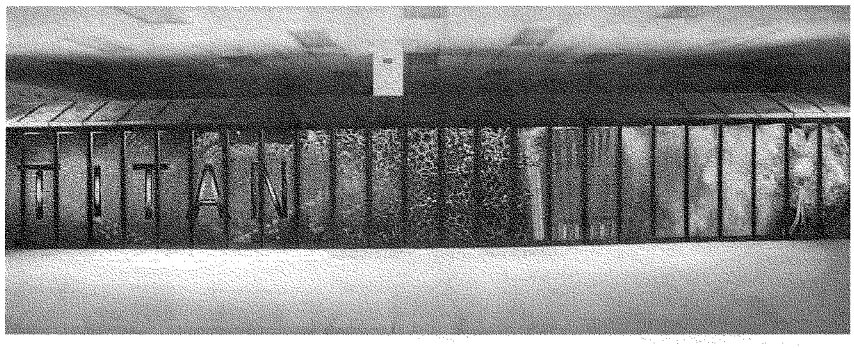
Improving reactor performance with predictive science-based simulation technology that harnesses world-class computational power

3D visualizations allow a physical walk-through of the top 20% of high-powered rods in a pressurized water reactor core. Details revealed provide insight into factors affecting core performance and aging. (Image courtesy of Tom Evans, ORNL).

Consortium for Advanced Simulation of Light Water Reactors

The Consortium for Advanced Simulation of Light Water Reactors (CASL) was established by the US Department of Energy in 2010 to advance modeling and simulation capabilities for nuclear reactors. CASL's mission is to provide computational capabilities that will make it possible to more accurately predict the behavior of phenomena that define the operational and safety performance of light water reactors (LWRs). In January 2015, the Department of Energy approved a second five-year phase for CASL, expanding its research and development activities through fiscal year 2019.

Through CASL, experts from national laboratories, universities, and industry are developing and deploying the Virtual Environment for Reactor Applications (VERA), a "virtual reactor" that can accurately simulate the physical processes taking place in a reactor at previously unattainable levels of detail. These processes include neutron transport, thermal hydraulics, nuclear fuel performance, corrosion, and surface chemistry. VERA incorporates science-based models, state-of-the-art numerical methods, modern computational science and engineering practices, uncertainty quantification and sensitivity analysis, and validation against data from operating reactors, experiments, and other sources to replicate these physical processes and to model their interactions.



Oak Ridge National Laboratory (ORNL) supercomputer, Titan, rated in 2014 as the leading HPC facility in the western world, supports CASL computational needs. (Image courtesy of ORNL)

CASL Achievements to Date

CASL is meeting milestones established by a well-defined yet flexible plan and delivering technologies that address industry issues. VERA has been deployed through "test stands" (prototype installations in actual engineering and design environments) and used to match actual startup and operations data for a Generation 2 reactor on the grid (the Tennessee Valley Authority's Watts Bar Unit 1) and to predict startup data for a Generation 3+ reactor design, the Westinghouse AP1000®, that is the basis for eight reactors now under construction. The CASL team is working to ensure that a subset of VERA, the VERA Core Simulator, can follow operational reactors through depletion, power maneuvering, and fueling cycles.

The models, methods, data, and understanding developed by CASL are being applied to create "useful and usable" tools to help the nuclear industry address three critical areas of performance for nuclear power plants (NPPs): (1) reducing capital and operating costs per unit of energy by enabling power uprates for existing NPPs and by increasing the rated powers and lifetimes of next-generation NPPs; (2) reducing nuclear waste volume generated by enabling higher fuel burnup, and (3) enhancing nuclear safety by enabling high-fidelity predictive capability for component performance through the onset of failure.

Innovations, Deployed Technologies, and an Effective Public-Private Partnership

- Integrated, goal-oriented, productive team spanning a geographically dispersed, heterogeneous set of organizations (national labs, universities, industry)
- Demonstrated, industry-reviewed predictions of reactor core behavior at previously unattainable levels of physical and geometric fidelity
- Multi-physics modeling and simulation of nuclear materials, corrosion chemistry, and fluids revealing insights that support enhanced operational maneuvering
- New fluid dynamics, chemistry, and materials modeling technologies that can resolve 3D reactor/fuel geometries via High Performance Computer oriented, advanced solution methodologies, for realistic nuclear fuel performance assessments
- Designer and researcher access to VERA's broad multi-physics simulation capabilities through a common "industry-friendly" interface for analyzing reactor operations

CASL Mission

Provide coupled, high-fidelity, usable capabilities needed to predict behaviors of light water reactor operational and safety performance-defining phenomena

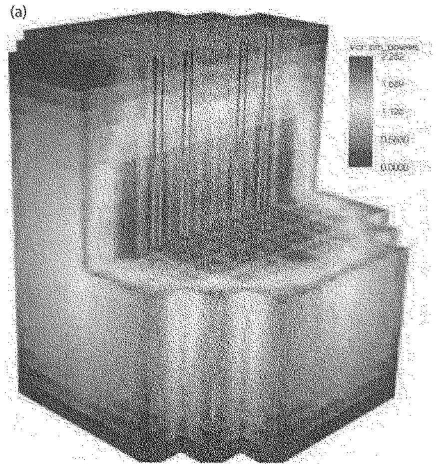
Strategic Goals

1. Develop and effectively apply modern virtual reactor technology (CASL's Virtual Environment for Reactor Applications: VERA)
2. Address design, operational and safety challenges for light water reactors (CASL Challenge Problems)
3. Engage the nuclear energy community through modeling and simulation
4. Deploy new partnership and collaboration paradigms

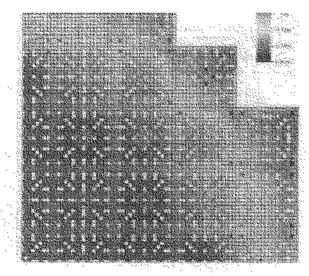
Illustration of VERA-CS Application to Integral Pressurized Water Reactor (iPWR) Small Modular Reactor (SMR)

The CASL VERA-CS is being used to model a four-year iPWR SMR cycle. The work has progressed to the 3D quarter-core calculations illustrated below: a) the 3D relative pin power distribution with a cutout section revealing the interior; b) the relative pin power distribution at the mid-axial plane; c) the core loading plan developed in the study associated with the power distributions.

(a)

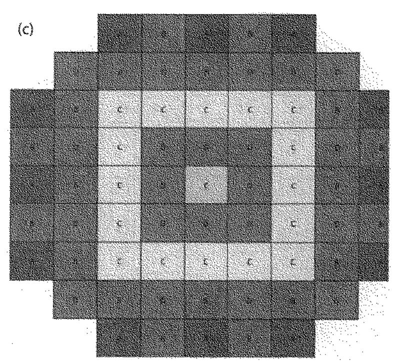


(b)



The white spaces in the image correspond to the pins that do not produce power (control rods and BPR pins).

(c)



Assembly Type	# Standard Fuel Pins	Standard Fuel Pin Enrichment	# Gd Fuel Pins	Wt% Gd
A	248	4.95	4	3
B	244	4.95	4	3
C	240	4.95	4	3
D	236	4.95	4	3
E	236	4.95	0	3

(Images courtesy of Kelly Kenner, Ivan Maldonado, University of Tennessee at Knoxville, Rose Montgomery, TVA, and Dudley Raine, B&W)

Achievements to Date

(FY 2010–FY 2014)

Year 1 . . .

- Technical roadmaps established for addressing high-priority Challenge Problems
- First high-resolution reactor core model for TVA Watts Bar plant
- First-of-a-kind three-dimensional (3D) assessment of fuel pellet-to-cladding interaction
- **VERA** founded with infrastructure and basic industry Core Simulator

Year 2 . . .

- Established methods for placing computer-based tools in industrial environments for real-life testing
- **VERA** produced neutronics simulation (prediction of changing neutron distribution in reactor core)

Year 3 . . .

- Expanded the neutronics capability to obtain unprecedented details on the movement of neutrons in a reactor core (demonstrated how to model the individual performance of thousands of fuel pins in an entire reactor)
- **VERA** internal release: Core neutronics + thermal hydraulics + fuel performance

Year 4 . . .

- Demonstrated application VERA tools to improve understanding of fuel-to-cladding interactions and the corrosion-induced power losses that result (reduding corrosion prevents power losses)
- **VERA** limited external release: Refinements to prior capabilities + corrosion and surface chemistry
- Completion and validation of VERA Core Simulator

Year 5 . . .

- **VERA** broad external release: Validate VERA with data from Watts Bar Unit 1 operating cycles and demonstrate CRUD challenge problem capababilites

Key Goals for 5 Year Extension

(FY 2015–FY 2019)

1. In it's second five-year phase, CASL will deepen its research and development for simulation of PWRs and broaden its applications to SMRs and BWRs through:
   - Fuel performance under accident conditions → further enhance safety of plants
   - Chemical and corrosion interactions between materials and coolants → reduce corrosion for longer-life plants
   - Two-phase thermal hydraulics for operational and transient reactor scenarios → more efficient plant performance
   - Expand to other types of reactors and reactors of the future → achieve industry-wide performance improvements
2. Develop the VERA core simulator kinetics capabilities and improve computational performance and accuracy → maximize value
3. Establish a self-sustaining organization, drawing from the CASL Industry Council, that is dedicated to the advancement and industry-wide deployment of VERA technologies → establish sustainable support for VERA

U.S. DEPARTMENT OF ENERGY Nuclear Energy

All narrative and images contained in this publication were provided for uses relating to the Consortium for Advanced Simulation of Light Water Reactors (CASL), which is managed at Oak Ridge National Laboratory by UT-Battelle for the U.S. Dept. of Energy.

Congressional Testimony

Jess C. Gehin
Director, Consortium for Advanced Simulation of Light Water Reactors
Oak Ridge National Laboratory

Before the
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives

Hearing on Department of Energy (DOE) Innovation Hubs

June 17, 2015

APPENDIX 2

CASL Virtual Environment for Reactor Applications Fact Sheet

CASL
A DOE Energy Innovation Hub

U.S. DEPARTMENT OF ENERGY

Virtual Environment for Reactor Applications (VERA)

Modern high performance computing (HPC) platforms bring an opportunity for modeling and simulation (modsim) at levels of detail previously unimaginable. Many of the complex phenomena occurring in light water reactors (LWRs) can be explored and better understood through the use of modsim able to exploit HPC.

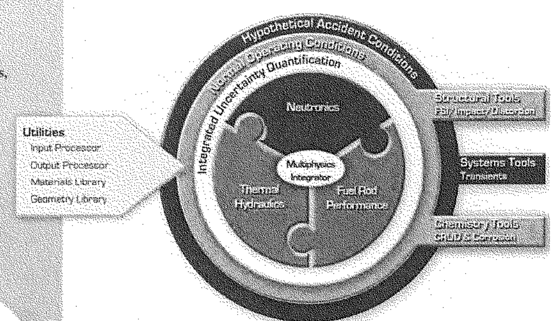
VERA bridges the gap between research and engineering by bringing together a suite of coupled software applications that simulate the behavior of a commercial LWR core under a variety of normal operating conditions. VERA integrates specialized knowledge of the multiple physics involved in nuclear power production by leveraging the contributions from leading scientists and engineers in government, industry and academia. As a result of this research, systems and processes can be engineered to higher levels of performance with longer and more productive lifetimes.

VERA incorporates science-based models, state-of-the-art numerical methods, modern computational science and engineering practices, and uncertainty quantification and validation using data from operating pressurized water reactors (PWRs), separate-effects experiments, and integral tests. The resulting Virtual Environment for Reactor Applications (VERA) will be among the most comprehensive and capable modsim toolset worldwide in the field of LWR science and technology.

CASL Founding Partners

CASL is focused on improving the performance of light water reactors with predictive, science-based simulation technology that harnesses the world-class computational power of ORNL's Titan high performance computer. VERA is being organized to rapidly advance the CASL mission through:

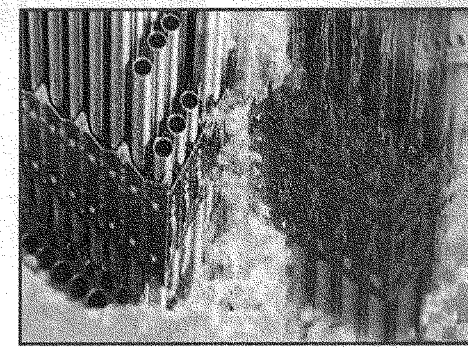
- Incorporating higher-fidelity modsim tools provided by DOE National Labs, academia, and industry into an integrated set of software tools for broad user access
- Coupling of the applications simulating the physics that drive reactor core performance
- Focusing on uncertainty quantification, validation, and verification of the applications
- Directly engaging stakeholders in the requirements driven research & development process
- Assuring that CASL products are effective and practical for ultimate use by designers and operators of LWRs in the future



VERA simulates a nuclear reactor core by using an integrated suite of computational tools that predict nuclear core performance based on the governing physics.

Bridging the Gap between Research and Engineering

New technologies are "game-changers" in research if they can rapidly advance scientific understanding and lead to better-engineered systems and processes that are optimized for performance. However, the translation from basic scientific findings to applied engineering solutions requires tools that are practical if they are to be broadly employed in practice. CASL is working to achieve a technology "step change" by creating a scalable set of applications delivered through a powerful integration infrastructure.



The foundation of CASL's coupled capabilities lies within the physics methods and numerical solutions encompassed within the VERA components. CASL's commitment to higher fidelity understanding of reactor phenomenona incorporates a rigorous 3D approach to the underlying scientific methodologies using explicit 3D techniques and utilizing leadership-class computing capabilities. Additionally, recognizing the need for higher-fidelity simulations on an industry-sized computing platform, CASL has elected to provide a scaled capability using alternative, less computationally intensive methods to allow for faster running on smaller computing clusters. Both higher-fidelity foundational capabilities represent a transformational advance in commercial LWR modsim through the physics coupling.

CASL Consortium partner Westinghouse Electric Company LLC has provided specifications for a commercial pressurized water fuel assembly (left) for explicit modeling using VERA (right).

A Virtual Nuclear Core

Many of the applications selected for CASL's VERA are general purpose codes; CASL has added a necessary layer of capabilities to the higher fidelity applications to track fuel through multiple commercial reactor cycles and to provide inventory information such as fuel depletion. CASL has also coupled several key feedback parameters such as fuel density and temperature and has demonstrated the strong effects of the feedback parameters on the simulation. Simulation of commercial LWR operational issues such as CRUD deposition using the higher fidelity coupled physics allows for better understanding and opens the door for better solutions. This coupled, higher fidelity capability sets a new standard of performance for LWR modsim and is unmatched anywhere in the nuclear science and engineering community. This capability has been tested on user computing platforms and through the deployment of VERA on CASL Test Stands.

Comparison of VERA with Typical Industry Core Simulator Methods

Physics Area	Typical Industry Core Simulator Method	VERA running on an Industry Class Platform	VERA running on a Leadership Class Platform
Neutron Transport	3-D diffusion (core) 2 energy groups (core) 2-D transport on single assemblies	2D/1D transport 23+ energy groups	3D transport 23+ energy groups
Thermal-Hydraulics	nodal average (1-D)	subchannel (w/crossflow)	subchannel (w/crossflow) or CFD
Fuel Performance	Bounding empirically-based	pin-by-pin (r,z) empirically-based	pin-by-pin empirically-based with some science based model
Fuel & clad Temperatures	nodal average & peak	pin-by-pin (r,z)	pin-by-pin
Power Distribution	nodal average with pin-power reconstruction	explicit pin-by-pin	explicit pin-by-pin
Depletion	infinite-medium cross sections, quadratic burnup correction history corrections, spectral corrections, reconstructed pin exposures	pin-by-pin with actual core conditions	pin-by-pin with actual core conditions
Reflector Models	1-D cross section models	actual 3D geometry	actual 3D geometry
Target Platforms[1]	workstation (six-core)	1,000 cores and up	10,000 cores and up

The Virtual Environment for Reactor Applications (VERA) provides a suite of simulation tools for analysis of physical phenomena in operating commercial nuclear fission reactors. It includes a spectrum of capabilities, with emphasis on advanced, high-fidelity approaches that provide unique and valuable insight into the behavior of reactors and effects of operational changes.

To find out more about VERA and to follows its research and development activity related to modeling and simulation of nuclear reactor cores, please visit www.casl.gov • casl-info@casl.gov

CASL

CASL-U-2013-042-002
ORNL 15-G00769/mhr

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APPENDIX 3

CASL Challenge Problems Fact Sheet

Consortium for Advanced Simulation of LWRs

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Challenge Problems . . . A Strategy that Demonstrates Progress

The nuclear industry employs a variety of science and engineering analysis techniques to understand and predict the performance of materials, components and subsystems involved in the diverse aspects of electric power generation. These analysis techniques, originating as far back as the 1960s and 1970s, have evolved over the past several decades as analytical methods have advanced and are validated based on experimental data from test reactors, commercial power reactors and unirradiated test loops.

Traditional industry simulation techniques are often based on the simplifying assumption that multiple and simultaneously interacting physical processes occurring can be conservatively bounded through simulation as uncoupled (independent), or loosely coupled (mildly dependent) processes. This approach has served the industry well and continues to support the safe operation of reactors and reliable performance of nuclear fuel. However, in order to achieve the key CASL challenges of enabling power uprates, increasing fuel burn-up and cycle length, and lifetime extension for U.S. nuclear plants, there is a need for higher fidelity tools and closely coupled tools. CASL's approach is to develop and apply modeling and simulation techniques that incorporate key science-based physical models, state-of-the-art numerical methods, and modern computational science into a useful and usable problem-solving simulation environment for nuclear scientists and engineers.

CASL's development plan is built around several issues relevant to operating commercial power reactors called "Challenge Problems" to drive development and demonstrate progress with results that can be applied to today's commercial power generation industry. CASL scientists are able to more precisely represent the normal operating conditions in a reactor. The integrated, coupled solutions are expected to reduce the uncertainties intrinsic in sequential analyses and provide a more realistic representation of the reactor behavior.

What is a Challenge Problem?

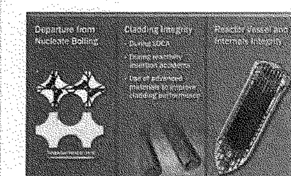
CASL is focused on a set of specific *Challenge Problems* that encompass phenomena currently limiting the performance of some pressurized water reactors. The Challenge Problems drive the development of the higher-fidelity coupled physics tools and demonstrate the application of the tools on existing issues, bringing immediate insights to the commercial nuclear power industry.

CASL defines a *Challenge Problems* as one whose solution is:

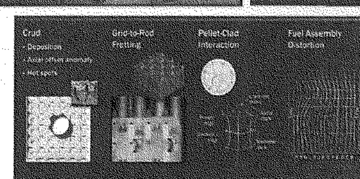
1. important to the nuclear industry and
2. amenable to, or enabled by, modern modeling and simulation techniques.

CASL Focuses on Selected Challenge Problems

Key safety-relevant reactor phenomena that limit performance



CASL is committed to delivering simulation capabilities for
- Advancing the understanding of key reactor phenomena
- Improving performance in today's commercial power reactors
- Evaluating new fuel designs to further enhance safety margin



Clear milestone-driven technical strategy for solving real-world reactor problems

Chalk River Unidentified Deposits (CRUD) and CRUD-induced Localized Corrosion (CILC)

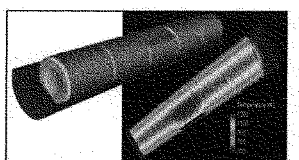
Decades ago, the unidentified deposits on Chalk River fuel elements were corrosion products from the reactor and steam generator piping; today it is known that the thickness of CRUD on the fuel is directly related to local rod power density. Thick CRUD deposits can lead to CILC and leaking fuel rods, and commercial power operations can be limited to reduce the risk of CILC failures. *Improved understanding could allow reactors to move to higher power densities.*

Grid-to-Rod-Fretting (GTRF)

Flow fields around the reactor fuel can cause the rods to vibrate against the supporting structures, eventually wearing a small hole through the fuel rod cladding. Some fuel designs are more vulnerable to vibration than others, and higher power operation and higher burn-ups can exacerbate the vulnerability. *Higher fidelity coupled physics simulations can provide a more comprehensive understanding of the design sensitivities leading to GTRF and allow for optimization of fuel designs to completely eliminate this failure mode.*

Pellet–Cladding Interaction (PCI)

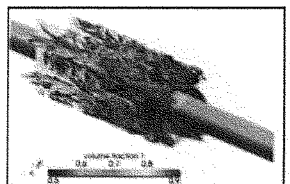
Commercial nuclear fuel utilizes pelleted uranium dioxide powder inside a zirconium-based alloy tube called "cladding." As-manufactured fuel rods include a small gap between the pellet and the cladding, and as the fuel rod is operated in the reactor, the cladding creeps down to rest on the pellet diametrical surfaces, resulting in pellet-cladding interaction. As power is varied, the pellet can swell or shrink, and the cladding tries to keep up. Very fast power changes can result in small tears in the cladding. Power uprates and increased burn-up reduce the ability for the cladding to keep up with power-induced pellet swelling, increasing the likelihood for cladding tears (fuel rod leaks). *Higher fidelity models could provide a high-resolution local simulation of the pellet and cladding behavior, providing a local best estimate (rather than bounding) performance margin for power maneuvers, insights into better pellet designs, and simulations of rod performance during postulated accident conditions.*



CASL PCI Simulation illustrating the local effects of a fuel pellet chip

Departure from Nucleate Boiling (DNB)

Nuclear reactors create electricity efficiently through the heating of the reactor coolant in a process called nucleate boiling. Departing from the nucleate boiling regime to a film boiling regime leads to local dryout of the cladding surface , causing a dramatic reduction in heat transfer capability during certain accident transients (e.g., overpower and low coolant flow). Predicting the critical heat flux (CHF) that causes the departure from nucleate boiling is currently accomplished through extensive, expensive testing and is highly design dependent. These empirical correlations do not allow for any extrapolation, and new fuel designs cannot be developed without a DNB test. *A science-based high fidelity simulation tool can allow for more efficient fuel designs and potentially allow or deriving more power from existing reactors.*



CASL Multi-field flow mixing proof of analytical concept

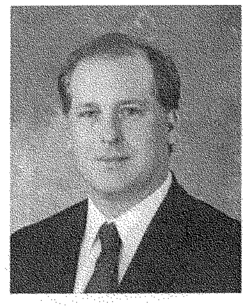
Cladding integrity during Loss of Coolant Accident (LOCA) or Reactivity Insertion Accident (RIA))

During an accident event, it is desirable to keep the fuel pellets contained within the fuel rod cladding. Maintaining the cladding integrity allows for containment of any fission products and provides a coolable fuel geometry. Predictions for cladding integrity during challenging accident scenarios are currently based upon a limited number of irradiated fuels tests. *A science-based high fidelity simulation tool can allow for better understanding of fuel performance, allowing for optimization of current designs and perhaps facilitating the development of future accident tolerant designs.*

CASL's Challenge Problem approach provides a flexible framework to drive development while providing near term insights for industry implementation. CASL's industry partnership allows for seamless industry integration and offers quick course corrections when needed.

CASL

Dr. Jess C. Gehin
Director, Consortium for Advanced Simulation of Light Water Reactors (CASL)
Oak Ridge National Laboratory



Dr. Jess Gehin joined the Oak Ridge National Laboratory in 1992 and is the Director of the Consortium for Advanced Simulation of Light Water Reactors (CASL). Previous positions at ORNL include leading Reactor Technology R&D Integration, Senior Program Manager, and Lead of the Reactor Analysis Group. Prior to this position, Dr. Gehin was a Senior R&D staff member performing research primarily in the area of nuclear reactor physics working on projects such as the development of the Advanced Neutron Source Research Reactor, Fissile Material Disposition, and modeling of experiments in the High Flux Isotope Reactor. Dr. Gehin earned a B.S. degree in Nuclear Engineering in 1988 from Kansas State University and M.S. (1990) and Ph.D. (1992) degrees in Nuclear Engineering from the Massachusetts Institute of Technology. Dr. Gehin also holds the position of Joint Associate Professor in the Nuclear Engineering Department and the Bredesen Center for Interdisciplinary Research and Graduate Education at the University of Tennessee. He is also an active member of the American Nuclear Society.

Research Interests

- Nuclear reactor physics computational methods for Light Water Reactors (LWRs) and advanced reactor concept development, design, and operations.
- Advanced nuclear reactor technology development including Fluoride salt-cooled High-temperature Reactor (FHR) and Molten Salt Reactor (MSR) concepts
- Nuclear fuel cycle systems and options analysis including fuel cycle evaluations to support R&D decisions and technical aspects of thorium-based fuel cycle systems.

Chairman WEBER. Thank you, Doctor.
Dr. Crabtree.

TESTIMONY OF DR. GEORGE CRABTREE, DIRECTOR, JOINT CENTER FOR ENERGY STORAGE RESEARCH (JCESR)

Mr. CRABTREE. Thank you, Chairman Weber and Ranking Member Grayson and Members of the Committee for this opportunity to testify. I will be talking about the Joint Center for Energy Store Research, otherwise known as JCESR, which addresses two compelling challenges: creating the next generation of high-performance, inexpensive electricity storage to transform transportation through the widespread penetration of electric cars, and to transform the electricity grid through widespread penetration of clean and sustainable wind and solar energy. JCESR concentrates exclusively on next-generation electricity storage beyond the reach of today's lithium ion technology.

Transportation and the grid account for 2/3 of all the energy used in the United States. Transforming them with high-performance, inexpensive storage not only modernizes our energy system but also grows the economy, creates jobs and promotes U.S. innovation in the global marketplace.

JCSER brings a new paradigm to battery R&D, integrating four functions into a single highly interactive organization, and those four functions are discovery science, battery design, research prototyping, and manufacturer collaboration. It is close interaction spanning across these four functions that accelerates the pace of discovery and innovation and shortens the time from conceptualization to commercialization. So JCESR's new paradigm is a model not only for battery R&D but also for other critical national energy challenges.

Using our new paradigm, JCESR intends to create two additional outcomes or legacies: a library of fundamental science of energy storage, applying the remarkable advances of nanoscience of the last 15 years to the materials and phenomena of energy storage at atomic and molecular levels, and the second outcome, using this new understanding to develop two prototype batteries, one for transportation, one for the grid, that when scaled to manufacturing have five times the energy density and one-fifth the cost of today's commercial lithium ion batteries. Although the two batteries may look very different, they will be based on the same library of fundamental science.

JCESR has already made substantial progress toward its goals. Soon after launch, we established our new paradigm spanning 150 researchers at 14 partner institutions. We began building the personal relationships that enable intense and effective communication, and we put in place the strategic objectives and the daily meetings that drive our program. In its first year, JCESR established three distinguishing tools so materials genome approaches for crystalline electrodes and liquid electrolytes that simulate tens of thousands of materials on the computer to find the most promising ones before they are ever made in the laboratory.

We also put together a unique electrochemical discovery lab to synthesize and explore these materials with state-of-the-art tools and the third distinguishing tool is techno-economic modeling to simulate the performance and cost of complete battery systems on the computer before they're prototyped.

So JCESR used these tools to make foundational progress in all four of its functional areas. We identified four promising directions for transportation and grid prototypes. We used our tools to converge these four battery prototypes so techno-economic modeling revealed the ultimate performance of each of the four prototypes and in an inverse process provided performance and cost thresholds for the materials that would make up the components of those batteries. The materials genomes found promising materials to meet these thresholds and the synthesis and prototyping teams began to build partial and complete prototypes to test the compatibility of the materials as complete battery systems. So we've met extensively with the private sector to discuss the size and performance of JCESR's prototypes that would be required to translate them to commercialization.

In our 2–1/2 years of operator, we've learned the critical importance of continuous improvement of our new paradigm. We worked closely with our 14 partners, our 150 researchers and our sponsor, the Office of Basic Energy Sciences in DOE, to refine our management practices, to refine our strategic directions, and to balance our exploratory divergent research to identify promising solutions with focused convergent research to implement and complete the selected solutions and prototypes rapidly.

During this time, we've terminated research on one candidate prototype—that would be lithium oxygen batteries—and initiated research on other promising opportunities including metal anodes for lithium and magnesium, and membranes for flow batteries. Nimble response to management and strategic challenges and opportunities as they arise is essential for completing our mission in a timely manner.

So thank you again for the opportunity to testify and I'm happy to answer questions later on.

[The prepared statement of Mr. Crabtree follows:]

Written Statement of

George Crabtree
Director, Joint Center for Energy Storage Research (JCESR)
Argonne National Laboratory
University of Illinois at Chicago

Before the
Subcommittee on Energy
Committee on Science, Space, and Technology
United States House of Representatives

Hearing on:
Department of Energy (DOE) Innovation Hubs

June 17, 2015

Introduction

Chairman Weber, Ranking Member Grayson, and Members of the Subcommittee, thank you for the opportunity to testify in today's hearing on *Department of Energy (DOE) Innovation Hubs*.

My name is George Crabtree, and I am Director of the Joint Center for Energy Storage Research (JCESR), comprising 14 partner institutions led by Argonne National Laboratory. Argonne is a U.S. Department of Energy, Office of Science multi-program national laboratory operated by the University of Chicago.

My comments will focus on three main areas:

1. What are the primary research and development goals of JCESR? Since the hub was organized by DOE, what progress has been made towards these goals?

2. How does the integrated research model employed at the hubs advance research goals within the Office of Sciences and applied energy program at DOE?

3. How does the private sector interact with JCESR? In what way does JCESR prioritize technology transfer of technologies developed by the hub?

What are the primary research and development goals of JCESR?

JCESR's *vision* addresses the two largest energy sectors in the U.S.: transportation and the electricity grid, which together account for two-thirds of our energy use. Our vision is aggressively transformative: to enable widespread penetration of electric vehicles that replace foreign oil with domestic electricity, reduce carbon emissions, and lower energy use; and to modernize the electricity grid by breaking the century-old constraint of matching instantaneous demand with instantaneous generation, enabling widespread deployment of clean and sustainable but variable wind and solar electricity while increasing reliability, flexibility and resilience. Both transformations can be achieved with a single disruptive breakthrough: high-performance, low-cost electricity storage, beyond today's commercial lithium-ion technology. JCESR's vision is to transform transportation and the grid with next generation beyond lithium-ion electricity storage.

JCESR's *mission* goals are to provide two prototypes, one for transportation and one for the grid, which, when scaled to manufacturing, are capable of providing five times the energy density at one-fifth the cost of commercial batteries in January 2012 when our proposal was prepared, summarized by the shorthand expression "5-5-5."

JCESR intends to leave three legacies

- A library of fundamental science of the materials and phenomena of energy storage at atomic and molecular levels
- Two research prototypes, one for transportation and one for the grid, that, when scaled to manufacturing, meet the 5-5-5 performance goals
- A new paradigm for battery R&D that integrates discovery science, battery design, research prototyping, and manufacturing collaboration in a single, highly interactive organization

Achieving these three legacies guides JCESR's strategic planning and provides metrics for evaluating its success.

JCESR supports distinguishing tools to accelerate energy storage research, including:

- The Materials Project and Electrolyte Genome to simulate the properties of tens of thousands of crystalline electrode and liquid electrolyte candidate materials on the computer to identify the few most promising candidates for synthesis and characterization in the laboratory,
- A unique Electrochemical Discovery Laboratory to create and study battery chemistries at atomic and molecular levels under high purity conditions, and
- Techno-economic models that build battery systems on the computer to project their performance and cost before they are prototyped

The beyond lithium-ion space is vast, rich and largely unexplored, with 50-100 distinct battery candidates that might deliver transformative performance and cost. To explore this space JCESR adopts a balance of exploratory "divergent" research to identify promising battery opportunities, and focused "convergent" research to design and build specific proof-of-principle research prototypes based on the most promising opportunities.

Exploratory divergent research is necessary to identify not only the one or two most promising candidates that JCESR intends to converge to prototypes but also the alternatives that serve as back up in case the selected batteries encounter unexpected fatal barriers during development. If these alternatives are not needed, they become viable candidates for second and third generation beyond lithium-ion batteries. Focused convergent research is necessary to produce specific functional prototypes from conceptual ideas by identifying and overcoming critical development challenges with a clear emphasis on outcomes.

What progress has been made towards these goals?

JCESR measures success by progress toward its three legacies and by tracking progress toward goals through a project management system. We have established an innovative and leading science effort in solvation and electrochemical reactions at interfaces of crystalline electrodes and liquid organic electrolytes, the central feature governing battery performance at atomic and molecular levels. The Electrolyte Genome has created a database of 15,000 organic molecules, from which candidates are being selected for use as liquid organic electrolytes in prototypes. The Materials Project has analyzed 1,800 combinations of multivalent working ions and crystalline electrodes for multivalent batteries, identifying three prime candidates now under experimental development and ten additional promising combinations as alternatives. The Electrochemical Discovery Laboratory has distributed custom designed high purity electrolytes to many research efforts across JCESR.

Many of the advances to date are documented on our website (http://www.jcesr.org). In the last year, ISI Web of Science has designated seven JCESR publications as "Highly Cited Papers" and one as a "Hot Paper," indicating their high impact in the science and technology community. To date, JCESR research has resulted in 26 invention disclosures with a dozen patent applications; additional applications are being prepared continuously.

JCESR has selected and begun to converge four next-generation prototype concepts. Techno-economic modeling has carried out system-to-materials analyses to identify threshold performance levels for the anode, cathode and electrolyte materials. Several candidate materials and batteries are being tested in half-cell and full cell prototypes. For information on specific science highlights from the past year, go to http://www.jcesr.org/highlights.

JCESR has already implemented and continuously refines its third legacy, a new paradigm for battery R&D integrating discovery science, battery design, research prototyping, and manufacturing collaboration in a single, highly interactive organization. JCESR's new paradigm accelerates the pace of discovery and innovation and shortens the time from conceptualization to commercialization. It enables the first two legacies, a fundamental understanding of the materials and phenomena of electricity storage at atomic and molecular levels, and the delivery of two prototypes, one for transportation and one for the grid, based on this fundamental understanding.

Since launch, JCESR has strategically refined its new paradigm for battery R&D in significant ways. We made a deliberate and strategic decision to terminate research on lithium-oxygen batteries and to emphasize research on lithium metal anodes. In the last year we introduced Sprints, focused 1- 6 month research efforts by small teams of 5-10 members to answer specific scientific questions central to prototyping.

At the end of each Sprint the results are published in peer-reviewed journals or circulated within JCESR in technical reports. The Sprints structure and focus our convergent prototype research, provide leadership opportunities for early career scientists, and quantify progress toward prototyping.

We established a computation-based dashboard for rapid comparison of alternative battery materials and designs, and introduced the practice of "prototyping everywhere" to better integrate prototyping with materials discovery and battery design.

These changes to JCESR's new paradigm have proven critical to accelerating the pace of discovery and innovation, enhancing communication among JCESR's four battery R&D functions and building personal relationships and trust among JCESR participants with different scientific and development perspectives.

How does the integrated research model employed at the hubs advance research goals within the Office of Science and applied energy programs at DOE?

JCESR's new paradigm integrates discovery science, battery design, research prototyping and manufacturing collaboration in a single, highly interactive organization. This integrated mode of operation not only promotes communication and accelerates progress but also provides a valuable link at the bench level among traditional science and technology perspectives and program offices spanning the Office of Science and the applied energy programs.

Many challenges in the RDDD chain do not fall neatly in a single category but require collaboration across one or more functions to achieve effective and timely solutions. JCESR encounters this frequently, for example in prototyping that reveals materials challenges and opportunities that require basic science solutions, or innovative battery approaches that emerge from basic science materials discoveries. These kinds of crosscutting interactions and innovations are easily missed in traditional compartmentalized approaches. Integration and communication are major strengths of JCESR and simultaneously advance the programs and outcomes of the Office of Science and the applied energy programs.

The hub model and JCESR's new paradigm create new modalities that could be applied to other critical national challenges. These "hub-worthy" challenges share some or all of the following characteristics:

- Solving the challenge creates a clear public good
- The solution has broad impact beyond the immediate context of the challenge
- There are no existing organizations capable or willing to meet the challenge
- The challenges require a coordinated and strategic approach bringing together diverse skills and capabilities under singular leadership with clearly defined outcomes

JCESR's experience in its first two years revealed several best practices that have become core operating principles. Among the most important are the value of in-person communication, sensitivity to organizational and management challenges and agility in addressing them. Continuous improvement of our new operational paradigm as we gain experience is a critical feature, as are balancing divergent and convergent research modes and changing directions early when new opportunities arise or established directions begin to founder.

To best serve the needs of the Department of Energy and accelerate the pace of discovery, JCESR is active in identifying and pursuing strategic collaborations and partnerships with the broader scientific community. JCESR scientists are well represented in the energy storage Energy Frontier Research Centers (EFRCs). At last count we share 19 senior scientists with the five energy storage EFRCs, ensuring close working relationships and rapid exchange of pertinent research results. In July 2015 JCESR and the EFRCs will jointly convene an energy storage workshop at Brookhaven National Laboratory to exchange information and plan complementary research.

JCESR has extensive interactions with programs in the DOE Office of Energy Efficiency and Renewable Energy, namely the Applied Battery Research (ABR) for transportation program and the new Battery Materials Research (BMR) program (formerly BATT), which aim to advance battery technology for electric vehicles. JCESR research interests in metal anodes, lithium-sulfur batteries, electrolytes and modeling are particularly relevant to the BMR program. JCESR diagnostic and prototyping research leverages the expertise in the ABR program.

How does the private sector interact with JCESR?

Connectivity to industry is critical to JCESR's vision and mission. We engage industry with a focus on licensing JCESR technology, scaling up JCESR prototypes for manufacturing, and guiding the direction of JCESR's research in industrially appealing directions. A few examples follow.

Licensing. JCESR continuously files invention disclosures and patent applications while seeking licensing opportunities with the private sector. To date, JCESR has pursued two licensing opportunities, one with an affiliate that is ongoing and likely to be completed in the near future and a second that was active for a year but has now been terminated at JCESR's request due to uncertainty surrounding possible eventual assignment to foreign entities.

Scale Up to Manufacturing. JCESR has interacted extensively with Johnson Controls (JCI), the largest manufacturer of lead-acid batteries, through in-person meetings to define the size and characteristics of a JCESR prototype that would meet the threshold criteria for Johnson Controls to consider for scale up to manufacturing. We agreed on target Battery Technology Readiness Levels for the JCESR prototype, the performance criteria including energy and energy density, power and power density, cycle life and charging rate. We outlined joint techno-economic modeling based on collaborative JCESR and Johnson Controls methodology that would predict ultimate performance and cost, and on a Battery System Level Requirements matrix that allows quantifying progress against success metrics in the form of a Gap Analysis. Faculty from University of Wisconsin-Madison will work collaboratively with JCESR scientists to create a manufacturing/lifecycle and supply chain analysis with specific emphasis on assessing scale-up risk factors.

Guiding the Direction of JCESR's Research. In addition to engagement with Johnson Controls, JCESR actively engages its industrial advisory boards and affiliate organizations on the direction of JCESR research and transition to commercialization.

In October 2014 JCESR convened a meeting of its Energy Storage Advisory Committee (ESAC). This committee includes representatives from General Electric, General Atomic, and Case Western Reserve University, among others. ESAC encouraged JCESR to clearly define the intent of the prototypes it develops, e.g., materials prototype, engineering prototype or product prototype. ESAC further encouraged JCESR to measure progress against project goals rather than against a simple linear time-based scale, which does not properly acknowledge the separate materials, component development and system integration steps of prototype development.

JCESR hosts annual affiliate meetings and regional events in order to better understand regional needs and connect researchers with private industry. These outreach events promote information sharing in the battery research community and future partnerships for the development and commercialization of new technologies.

In March 2014 JCESR held its first annual affiliate meeting at Argonne. The event was attended by 70 individuals from more than 50 organizations, spanning universities, national laboratories, research organizations, non-profits, start-ups, large corporations, and local government.

In October 2014 JCESR held its first regional event at the University of Illinois-Champaign Urbana. The event focused on stationary energy storage applications and was attended by 120 people from industry, national laboratories and academia.

In November 2014 JCESR held its second regional event in Buffalo, New York. Co-sponsored with NY-BEST, the event featured highlights from two energy storage EFRCs in the Northeast. JCESR and the two EFRCs discussed the complimentary nature of their research and opportunities to exchange breaking results. Approximately 120 people attended this event.

In May 2015 JCESR held its second annual affiliate meeting at the University of Chicago, attended by approximately 75 people. JCESR highlighted the research of some of its early career scientists. The meeting included two breakout sessions to seek feedback from the affiliates on technological and commercial opportunities and success metrics.

In June 2015 JCESR held a Chicago Regional event focused on educating high school students on energy storage at the University of Chicago, attended by approximately 80 students from the Chicago area.

JCESR participated in two grid energy events in Anchorage, Alaska in March 2015: the Remote Community Renewable Energy Workshop and the Islanded Grid Wind Power Conference. Alaska acutely needs clean, inexpensive, and easy to implement energy sources for Alaskan islanded grid communities. Through events like these and the JCESR regional affiliates events, we aim to fully comprehend the breadth of the nation's energy challenges so that we can align our resources to tackle key challenges and ultimately refine our vision.

JCESR is helping to organize the 2015 Electrochemical Energy Summit (Solar Critical Issues and Renewable Energy) in conjunction with the 228th Electrochemical Society Meeting in October 2015 in Phoenix Arizona, emphasizing strategies to foster public-private partnerships and team science and integration in the paradigm of basic-to-applied research. Efforts to secure participation from international hubs in Japan, Germany, France and England are underway. JCESR recently joined forces with the University of Illinois at Chicago and the Illinois Institute of Technology to kick off the revitalization of the ECS Chicago Section, which promises to concentrate energy storage electrochemistry expertise in the Chicago area.

In what way does JCESR prioritize technology transfer of technologies developed by the hub?

JCESR prioritizes transfer of its technology through its intellectual property (IP) management plan, designed to lower the barriers to collaboration and promote access to JCESR-funded IP. JCESR's IP management tools include (1) a novel, member-agreed-upon management plan and umbrella nondisclosure agreement (NDA), (2) dedicated staff that proactively manages IP across the consortium, and (3) proactive identification of high-value research areas and potential commercialization outlets.

At the time the JCESR proposal was submitted, the JCESR members had already executed an IP management plan, which among other things pooled JCESR-funded IP for centralized licensing and established the Intellectual Property Management Council (IPMC). The IPMC consists of representatives (technology transfer or legal personnel) from each member institution and is led by JCESR's Intellectual Property and Business Development Manager. The council meets regularly and manages issues relating to IP within the hub. For example, since July 2014, the IPMC has met to discuss various aspects of potential licensing negotiations. These discussions are able to take place because JCESR has an umbrella nondisclosure agreement that covers all JCESR-related discussions among members. This umbrella NDA also authorizes Argonne, as the lead institution, to sign JCESR NDAs on behalf of the partnership. Additionally, JCESR established a management position that anyone who receives JCESR funding must agree to the terms of the IP management plan and the NDA, including new participants who were not signatories to the original agreements. This policy reduces the barriers to collaboration and allows for effective and efficient information sharing among the researchers, regardless of institutional affiliation. JCESR has seen evidence of this success by the number of multi-institutional projects that are now occurring.

The Venture Advisory Council is a consortium of venture capital firms that evaluates JCESR technologies for early spin-out or licensing, expediting the commercial impact of JCESR work. The Venture Advisory Council meets twice annually, offering feedback on business challenges addressable by JCESR technology, helping measure market potential, informing JCESR of competing companies and suggesting valuable commercial partners from their networks.

Summary

JCESR's experience in the first half of its five-year term indicates that its new paradigm for integrated research, embracing discovery, design, prototyping and manufacturing is viable and effective for battery R&D and could be a model for other critical national challenges with transformative potential. We have implemented mechanisms for communicating and collaborating across JCESR's four functional areas, for strategically identifying, planning, implementing and managing research distributed across multiple institutions, and for refining our new paradigm in response to emerging challenges and opportunities.

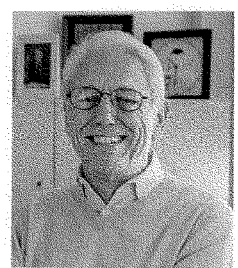
We have made significant progress toward each of our intended legacies and goals: a library of fundamental science of electricity storage at atomic and molecular levels; delivering transformational prototype batteries for transportation and the grid; and establishing a new paradigm for battery R&D. The functional integration from discovery to manufacturing accelerates the pace of discovery and innovation and advances the research goals of the Office of Science and the applied energy programs. JCESR opens new doors to the private sector spanning licensing, collaboration to identify and pursue strategic research directions and smoothing the technology transition to industry.

We look forward to significant additional innovation and progress in the second half of our five-year term.

Thank you again for the opportunity to testify and I look forward to answering any questions you may have.

Biography

George W. Crabtree



George Crabtree is Director, Joint Center for Energy Storage Research (JCESR) and Distinguished Professor of Physics, Electrical, and Mechanical Engineering at University of Illinois at Chicago. He has won numerous awards for his research, including the Kammerlingh Onnes Prize for his work on vortices in high temperature superconductors. This prestigious prize is awarded once every three years; Dr. Crabtree is its second recipient. He has won the University of Chicago Award for Distinguished Performance at Argonne twice, and the U.S. Department of Energy's Award for Outstanding Scientific Accomplishment in Solid State Physics four times, a notable accomplishment. He has an R&D 100 Award for his pioneering development of Magnetic Flux Imaging Systems. He is a Fellow of the American Physical Society, a charter member of ISI's Highly Cited Researchers in Physics, a member of the U.S. National Academy of Sciences and a Fellow of the American Academy of Arts and Sciences.

Dr. Crabtree has served as Director of the Materials Science Division at Argonne, as Chairman of the Division of Condensed Matter of the American Physical Society, as a Founding Editor of the scientific journal Physica C, as Divisional Associate Editor of Physical Review Letters, as Chair of advisory committees for DOE and NSF research centers and as Editor of several review issues of Physica C devoted to superconductivity. He has published more than 400 papers in leading scientific journals, has collected over 16,000 career citations, and has given over 100 invited talks at national and international scientific conferences. His research interests include next generation battery materials, sustainable energy, energy policy, materials science, nanoscale superconductors and magnets, and highly correlated electrons in metals. He co-chaired the Undersecretary of Energy's assessment of DOE's Applied Energy Programs. He has testified before the U.S. Congress on the hydrogen economy and on meeting sustainable energy challenges.

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Chairman WEBER. Thank you, Dr. Crabtree.
Dr. King.

TESTIMONY OF DR. ALEX KING, DIRECTOR, CRITICAL MATERIALS INSTITUTE (CMI)

Mr. KING. Thank you, Chairman Weber, Ranking Member Grayson, Members of the Subcommittee. Thank you for the opportunity to testify at today's hearing on innovation Hubs.

I'm Director of the Critical Materials Institute, which is led by the Ames Lab in Ames, Iowa, the U.S. Department of Energy Office of Science National Lab operated by Iowa State University. CMI's team includes more than 300 researchers and support staff across six corporations, seven universities and four national labs.

CMI exists primarily to mitigate the challenges posed to the manufacturing sector by materials that provide essential functions or capabilities but are subject to supply risks. The Hub focuses on materials used in clean energy technologies, but many of these have broader uses, notably in the area of defense. Prominent among the Hub's research targets are the rare earth elements, which are used in magnets, lighting and displays, and lithium, which is used in today's rechargeable batteries.

CMI follows the critical materials strategic developed by the U.S. Department of Energy, addressing opportunities in three areas: One, diversification of supply; two, development of substitute materials; and three, improving the efficiency of materials used in reducing waste in our access of the currently available materials.

Within its first five years, this Hub will develop and have adopted by industry at least one technology in each of these three areas. In its first two years of operation—we just celebrated our second anniversary—CMI has developed 34 inventions with significant potential for impact, has made four patent applications. It is very close to having one replacement material adopted by an industrial and is within a year or two of a second. Materials development of this kind typically takes 20 years, and we've succeeded in two. Maybe I'll explain how later. CMI-developed technology for solvent extraction is being considered for licensing by two mining companies as we speak.

These results have strong potential for providing financial returns on the investments made by the U.S. taxpayer. The Hub has earned an international reputation and has been described as the gold standard in its field. Several other countries are modeling their own efforts after CMI.

How does this integrated research model advance the goals of the Office of Science and Applied Programs at DOE? Let me offer an example. In pursuit of new magnet models, we combine, as other Hubs do, computer simulations, experimental exploration of candidate alloys, rapid analysis and testing. These methods are all founded upon tools previously developed among CMI's partners largely with DOE Office of Science Support, but we have advanced them and made them specific to our own purposes. So the Hub has in its first two years developed the first successful theory and computer models for predicting what is called magneto-crystalline anisotropy—maybe I'll explain if you ask—for proposed new materials. This is something that hadn't been possible before. It's a contribution from fundamental condensed matter physics in support of developing new magnetic materials.

We've developed a tool based on additive manufacturing technologies for the rapid production of target magnet compositions, allowing us to produce arrays of materials that can then be tested. We've built new capabilities actually in collaboration with JCAP for rapid analysis of materials that take advantage of our additive manufacturing tool, and we have added high-throughput magnet testing capabilities. All of these capabilities work together to produce new materials, make them, test them, and meet the needs of the Hub. They are also enhancing the capabilities of other Office of Science and EERE programs, bringing them together. We have created a range of candidate materials for new high-performance magnets.

Effectively, what we have done is to orchestrate diverse scientific efforts and enhance them so that we're able to meet technological needs of the day in short order. We're able—we've demonstrated the ability by doing that to go from zero to having new materials invented in two years, a process that typically takes up to 20.

How does the private sector interact with CMI? We are very flexible. We seek—we have always sought to be flexible and responsive to industry needs. We find that our research goes faster when we speak to industry because speaking first we listen. We foster increasingly intensive collaborations as companies move from informal interactions to membership in our affiliate program to full engagement as research team members. Some companies have also expressed interest in engaging CMI for proprietary pre-commercial research, and we are considering that opportunity.

Technologies developed by the Hub using its federal funds must be pre-competitive, must have high potential for impact on the supply chain, must be cost-effective, timely and have potential for adoption by U.S.-based companies.

Thank you.

[The prepared statement of Mr. King follows:]

Accelerating Energy Innovations

Critical Materials Institute
AN ENERGY INNOVATION HUB

Congressional Testimony

Committee on Science, Space, and Technology
Subcommittee on Energy
U.S. House of Representatives

June 17, 2015

Alexander H. King, CMI Director

SUMMARY

The Critical Materials Institute (CMI) exists to mitigate the challenges posed to the manufacturing sector by materials that provide essential functions or capabilities, but are subject to supply risks.

The hub focuses on materials used in clean energy technologies, but many of these have broader uses, notably in the area of defense. Prominent among the hub's research targets are rare earth elements that are used in magnets, lighting and displays; and lithium which is used in rechargeable batteries.

CMI follows the Critical Materials Strategy developed by the U.S. Department of Energy, particularly addressing opportunities to (1) diversify supply, (2) develop substitute materials, and (3) improve efficiency of materials use, and reduce wastes. Within its first five years, the hub will develop, and have adopted by industry, at least one technology in each of these three areas.

The hub adopts an integrated approach, bringing together capabilities across a wide spectrum of basic and applied research, and researchers across a wide range of backgrounds, to accelerate the achievement of specific technological goals. After two years of operation, this approach is already proving its worth.

CMI has developed 34 inventions with significant potential for impact, and has made four patent applications. It is very close to having one replacement material adopted, and is within a year or two of a second. These results have strong potential for providing returns to the U.S. taxpayer.

The hub has earned an enviable international reputation and has been described as the "gold standard" in its field. Several other countries are modeling their own efforts after CMI.

CMI's team includes more than 300 researchers and staff across six corporations, seven universities and four national laboratories.

Background

In 2010, the prices of materials based on the rare earth elements spiked, in some cases rising to 25 times their prior values. While these materials are used in relatively small quantities, they are functionally essential, and presently irreplaceable in a wide range of industries, including the production of clean energy technologies and modern weapons systems.

The 2010 price spike resulted from uncertainty about the ability of supplies to keep up with demand for neodymium and dysprosium in high-performance magnets, and yttrium, europium and terbium in high-efficiency light sources.

As supply uncertainty grew, technology choices were impacted across the U.S.:

- Direct-drive wind turbines are quieter, more efficient, and less failure prone than competing technologies but they represent less than 1% of utility-scale installations in the U.S., because of their demand for neodymium and dysprosium. Almost all utility-scale wind turbines in the U.S. use alternative technologies requiring gearboxes, that are noisier, less efficient and more failure-prone.
- Rules promoting the general use of high-efficiency T5 fluorescent lamps were delayed in the U.S. because of the technology's demand for europium and terbium.

Analyses focusing on a variety of different industries, countries and regions have identified several additional materials that are at risk for similar supply disruptions and downstream impacts on technology. These are called critical materials, and industry's vulnerability to them has become a worldwide topic of concern.

Responses to supply-chain shortfalls generally include three approaches:

- Diversification of supplies. A major factor causing criticality is the concentration of supply in a single company, country or region, resulting in unacceptable supply uncertainty, and, hence, unacceptable supply risk.
- Development of substitute materials. The need for materials properties and functions, such as magnetism or fluorescence, which are conferred only by specific elements is also a major factor in making those materials critical.
- Minimizing the draw-down of existing supplies by improving manufacturing efficiency and enhancing recycling and re-use. When the rate of use approaches the rate of production, a material tends to become critical.

In order to be effective, these solutions must be cost effective, and achievable in a timeframe that compares with the speed with which supply shortfalls emerge.

The Critical Materials Institute exists to promote these solutions. Its work focuses initially on the elements neodymium, dysprosium, europium, terbium, yttrium and lithium, but its methods and approach will be applicable to other critical materials as they emerge.

What are the primary research and development goals of CMI? Since the hub was organized by DOE, what progress has been made towards these goals?

5-Year Goal

- To develop at least one technology and have it adopted by industry in each of the three priority areas identified by the DOE *Critical Materials Strategy*[1]: (1) diversifying supply, (2) developing substitute materials, and (3) improving efficiency of materials use, including reducing wastes.

Research

- CMI's current research focuses on neodymium and dysprosium (used in permanent magnets); europium, terbium, and yttrium (fluorescent and LED lighting); and lithium (batteries)—all identified as "critical" or "near critical" in DOE's Critical Materials Strategy.
- CMI aligns its research and development efforts with the three priorities of the DOE *Critical Materials Strategy*. In addition, CMI carries out research cutting across and supporting progress in these areas, including fundamental research in chemistry and physics, environmental impacts, and economic and business analysis.

Basic Information

- The Critical Materials Institute (CMI) began operations on June 1, 2013, and is one of four Energy Innovation Hubs funded by the U.S. Department of Energy (DOE).
- Its mission is to assure supply chains of materials essential to clean energy technologies—enabling innovation in U.S. manufacturing and enhancing U.S. energy security.
- Led by the Ames Laboratory, CMI brings together facilities and expertise located at six U.S. corporations, seven universities, and four DOE national laboratories. A number of additional corporations are collaborating with CMI in a range of capacities.

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[1] *Critical Materials Strategy*, US Department of Energy, Washington, DC, December 2011.

Achievements to Date

Among CMI's accomplishments so far, we have:

- Formally announced 34 invention disclosures and filed four patent applications.
- Published 30+ archival technical papers.
- Made over 70 presentations at conferences and meetings, with the majority of them being keynote or invited presentations.
- Drafted a new materials criticality matrix, assessing "what is critical" for clean energy technologies looking fifteen years into the future.

Supporting and facilitating these achievements, we have:

- Built an outstanding and highly capable research team of over 300 scientists, engineers and support staff.
- Completed all major equipment acquisitions, providing unique and focused tools for the hub's work.
- Generated detailed technological roadmaps for all of our research projects.
- Established a broad network of industrial collaborations.
- Established an exceptional level of global visibility.

How does the integrated research model employed at the hubs advance research goals within the Office of Science and applied energy programs at DOE?

CMI is funded through DOE's Advanced Manufacturing Office (AMO), an applied energy program, but it is headquartered at the Ames Laboratory, which is an Office of Science national laboratory. By design, the hub is integrated across the spectrum of basic and applied research as necessary to achieve its goals, and has the ability to draw on resources developed by the Office of Science, as needed, in pursuit of the goals of the Advanced Manufacturing Office. The hub has the structure and the connectivity to access facilities from the Office of Science and EERE as needed.

For one example, in pursuit of new magnet materials to replace neodymium-iron-boron, we have adopted an approach that includes computer simulations, experimental exploration of candidate alloy compositions using combinatoric methods, and rapid analysis and testing. These methods are each founded in tools previously developed among CMI's partners, largely with Office of Science support, but they have been advanced and made specifically useful for CMI's purposes by the hub itself. Among many other advances of this kind, the hub has:

- Developed the first successful computer model for predicting magneto-crystalline anisotropy in proposed new materials - an essential contribution from fundamental condensed matter physics in support of developing new magnet materials.
- Developed a new tool, based on additive manufacturing technologies, which allows for the rapid production of target magnet compositions at manufacturing scale. This tool along with the two below, was used to validate the computer code described above.
- Added new capabilities for rapid structural and chemical analysis of materials that take advantage of the additive manufacturing tool described above.
- Added high-throughput magnetic testing capabilities.

All of these capabilities work with each other to meet the needs of the hub, but they also enhance the capabilities of other Office of Science and AMO programs. Bringing together capabilities across all of CMI's participating institutions, across a wide spectrum of basic and applied research, we have created a range of candidate materials for new high-performance magnets.

While it is conceivable that these advances could have been made without the existence of a hub, under the usual operating procedures, even this simple case would have required four separate projects to have been funded through regular Office of Science or EERE programs to develop the tools, and then a fifth funded program to work on the desired material. We hesitate to speculate about the likelihood of all of these components coming together without the existence of a hub.

As illustrated in this example, CMI identifies significant expertise, capabilities and tools from across the DOE complex and its other partners, enhances them as needed, and integrates them in the context of research efforts to meet specific needs. This enables us to obtain essential outcomes rapidly, across a wide range of technology readiness levels (TRLs) in support of our applied research and development goals.

In addition to being integrated across technology readiness levels (TRLs), the hub brings together the full range of technical skills needed to address challenges at any point in the supply-chain, from extracted minerals, to materials, to components, to devices, to re-use and recycling, including economic analysis of every aspect. The hub's economic analysis capabilities provide an essential filter, helping us to identify the most promising technological points of intervention and focus our resources where they are most likely to have the desired impact.

CMI's ability to identify key points of intervention, and to integrate capabilities and facilities to address them, enable it to accelerate the development of solutions to supply-chain challenges very significantly.

In the case of finding replacement phosphors for fluorescent lighting, for example, after two years of work we are already very close to getting one new material adopted by industry, and a year or so away from a second. This compares with the typical materials adoption timescale of around 18 years. As noted in the background section, the ability to respond quickly is a key capability in addressing supply-chain challenges, and we are already demonstrating significant advancements in this area.

How does the private sector interact with CMI? In what way does CMI prioritize technology transfer of technologies developed at the hub?

CMI has several means of interacting with corporations in the private sector and seeks to be flexible and responsive to industry needs. It has been our observation that progress toward our goal of technology adoption is accelerated – often very considerably – when industry input is obtained early and often during our research efforts. Our interactions with industry allow for and promote increasingly intense collaborations as a company moves from one mode to another. CMI covers a wide range from basic research to commercialization, and the discussion, below, moves generally from the basic end of the spectrum toward industrial applications.

Our cross-cutting research efforts produce basic knowledge, information or tools that are of specific value to the applied research, development and demonstration (RD&D) projects described below. These projects generally do not produce intellectual property and are characterized by very low technology readiness levels (TRLs). Research outcomes from this type of work are generally published in the open literature and made available through the usual means.

Our research and development efforts on source diversification, materials substitution and minimizing the draw-down of existing resources all proceed to progressively higher TRLs, and every project has a specific commercialization goal and a roadmap that guides the decision-making process for the project. Most of these projects interact with the private sector in one or more of the modes described below:

- Informal interactions, usually facilitated by appropriate bilateral non-disclosure agreements (NDAs), allow us to respond to inquiries from the corporate sector, or to reach out to corporations that might have information useful to CMI researchers, or potential interest in CMI-developed technologies. These interactions may lead to enrollment of the corporate entity in our Affiliates program, or as a Team Member. Interactions of this type are increasingly being conducted in the form of industry-sector workshops.

- CMI's corporate *Affiliates* share information with CMI's researchers. Contributing funds through a sliding scale of fees, they provide input and advice to CMI researchers and have early access to CMI's research results. The Affiliates program is designed to cultivate potential corporate Team Members. Affiliates sign a uniform joint NDA, allowing them access to federal or affiliate-funded CMI information.

- CMI's corporate *Team Members* are actively engaged in our research programs on pre-competitive technologies. They contribute materials, facilities and/or expertise. In many cases they are anticipated to be the primary partners for commercialization of CMI-developed technologies. Team Members are bound by a uniform joint NDA and an intellectual property management plan (IPMP), which provides them with the right of first refusal to license CMI-developed technologies.

- Any corporate entity has the right to negotiate a license to the federally funded IP developed through the CMI that is not exclusively licensed in a field or fields of use to Team Members.

- CMI also has the ability to collaborate with the private sector through Strategic Partnership Programs (SPPs) and Cooperative Research and Development Agreements (CRADAs) that, respectively, involve the corporate entity paying for specific projects to be performed, or collaborating in a specific research project on a "funds-in" basis. In both cases, the sponsoring corporation may own new IP generated by the project, subject to standard federal stipulations. These funding mechanisms are appropriate when a technology advances from the "pre-competitive" stage to "pre-commercial."

All projects carried out under the auspices of CMI are targeted toward commercialization, and to that extent, prioritization takes place initially, when the hub elects to pursue (or drop) a particular line of research. Decisions to add or drop projects are made annually, as the hub approaches the anniversary of its inception, and choices are based upon the following criteria:

- Pre-competitive nature. Work initiated by the hub is not intended to benefit any single corporation, but to have potential for broad utilization among all corporations in the appropriate industry sector.

- Necessity for impact. The work must have a reasonable prospect for success, and if successful, a strong prospect of making significant impact on the supply chain of one or more critical material.

- Cost considerations. The technology will meet or exceed the cost points necessary for adoption by the appropriate industry sector(s). Costs include the cost of the material, and, usually more significantly, the costs to integrate new materials and/or processes into each company's product lines.

- Timeliness. Technologies developed by CMI must enter the industrial sector at an appropriate time in the product development lifecycle in order to have an impact.

- Preference for U.S. companies. There should be at least one U.S.-based company at which the technology would be considered for adoption. Foreign corporations with substantial operations in the U.S. are also considered as commercialization partners.

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Alex King was born and raised in London. He attended the University of Sheffield as an undergraduate and earned his doctorate from Oxford. He was a postdoc at Oxford and then M.I.T. before joining the faculty at the State University of New York at Stony Brook, where he also served as the Vice Provost for Graduate Studies (Dean of the Graduate School). He was the Head of the School of Materials Engineering at Purdue in from 1999 to 2007, the Director of DOE's Ames Laboratory from 2008 until 2013, and since June 2013 he has been the Director of the Critical Materials Institute – one of DOE's four Energy Innovation Hubs.

A distinguished teacher and researcher, King is a Fellow of the Institute of Mining Minerals and Materials; ASM International; and the Materials Research Society. He was also a Visiting Fellow of the Japan Society for the Promotion of Science in 1996 and a US Department of State Jefferson Science Fellow for 2005-06.

Alex King was the President of MRS for 2002, Chair of the University Materials Council of North America for 2006-07, Co-chair of the Gordon Conference on Physical Metallurgy for 2006, and Chair of the APS Interest Group on Energy Research and Applications for 2010.

Chairman WEBER. Thank you, Dr. King. I thank the witnesses for your testimony. I now recognize myself for questions for five minutes.

Dr. Gehin, as I noted in my opening statement, CASL's support for NRC license renewals is an issue of particular importance to my district and my adjoining Matagorda County, Blake Farenthold's district. The South Texas Project Units 1 and 2 are currently under review by the NRC to operate for an additional 20 years, which means 20 more years of safe, reliable, and, I might add, zero-emission power for Texans. Can you explain to us generally how CASL's simulation capabilities uniquely allow the use of supercomputers to model the integrity of a reactor pressure vessel and other components and why this is important for license extensions for the reactor fleet to operate up to 80 years. Doctor?

Dr. GEHIN. Thank you very much for the question. So in a life extension of a reactor, you need to consider the aging of the materials, and so this is being done for the current 20-year life extensions. What we're interested in is informing the next 20-year extension which, as you have noted, 60 to 80 years. So it will not impact the current—CASL will not impact the current license renewal, which is already in process.

When you look at the extension to 60 to 80 years, there are critical components in the reactor that can't easily be replaced. One of these is the reactor vessel. There's others that are concrete and other materials.

Chairman WEBER. Let me ask you real quick right in here because I read that in your comments. Why is it that the reactor core cannot be replaced? Is it just cost prohibitive?

Dr. GEHIN. It's cost prohibitive. It's very—it would be very invasive to extract the vessel, or the reactor vessel, which is right in the center of the reactor. So it's not deemed as being cost-effective to replace.

Chairman WEBER. Okay. That's strictly based on cost considerations?

Dr. GEHIN. Yes.

Chairman WEBER. Okay. Thank you. Go ahead.

Dr. GEHIN. And so—but the integrity of that vessel is really very important, of course, for safety and operation reasons so it's important to look at its integrity, and which was done extensively, and renewals. What we're doing in CASL by using our supercomputing capabilities is be able to do a very precise calculation of the neutron interactions on that vessel. So the vessel surrounds the fuel and so neutrons, you know, move around in the core, hit the vessel, and affect its material properties. So by being able to better follow the operation of the reactor over its lifetime and calculate the neutron interactions in a better way, three-dimension, higher fidelity, you can combine that improved material models that are being developed to understand the condition of that vessel and ensure that it can be extended another 20 years.

Chairman WEBER. We were talking earlier when I came out to introduce myself to you all about criticality.

Dr. GEHIN. Yes.

Chairman WEBER. How long does it take to reach criticality, for example?

Dr. GEHIN. You know, they load the fuel, and it might take, you know, a day or two to become critical and then there's an escalation of power over a couple days, and then the intention is to operate at full power. Critical means operating exactly steady state power. That's where you want a reactor to operate for 18 months. That's the goal. Then you shut down for refueling.

Chairman WEBER. So once you reach criticality, and you've got—forgive me, this is very technical—neutrons. Explain that process.

Dr. GEHIN. So the goal in achieving criticality or steady state operation is to have a self-sustaining neutron chain reaction, and so you get neutrons that are produced by fission and you have those in balance such that they cause additional fissions that create more neutrons so you maintain a steady state.

Chairman WEBER. Right, and of course, I'm a layman in this, but it just seems like once you reach criticality, you know the effect on the reactor core.

Dr. GEHIN. Well, you know—so when you reach criticality, you are impacting the fuel. You're depleting the fuel. You're irradiating the vessel, irradiating the components, and most importantly, generating power, which is the whole reason you're doing this. So while you're doing that, you do not know the full three-dimensional distribution of fluids on the vessel. You make measurements in selected locations to confirm the material behaviors is as expected. But what we can add with CASL is a lot more detail on what can actually be measured.

Chairman WEBER. Are you measuring inside and outside the vessel?

Dr. GEHIN. Yeah. They insert what's called coupons. They're metal samples that they can then take out of the reactor and interrogate. So one thing is really important. Simulation alone can't provide this information, simulation combined with this type of data and experiments that can give the complete picture.

Chairman WEBER. Are you able to anticipate new materials? I know we talked about graphite being used, heavy water, light water.

Dr. GEHIN. Yeah.

Chairman WEBER. Are you able to extrapolate that to what those effects would be on the reactor core itself?

Dr. GEHIN. Yes, and the tools we're developing are based on more fundamental principles than typical design tools so they'll accommodate different material—consideration of different materials. It's particularly valuable in scoping calculations, what if we did this, how would it perform, so you could down-select the most promising concepts that you could then take forward. You know, this is looking at fuel designs and how you operate the reactor can give you a lot more additional information.

Chairman WEBER. Okay. Forgive me, I'm way over my time, but I did have a question for Dr. Crabtree. I think you're working on the batteries. All I want to know is, can you make it where my iPhone battery doesn't run down while I'm watching the grandkids on videos?

Mr. CRABTREE. Great question, and I have the same challenge. I wish my iPhone lasted twice as long.

Chairman WEBER. Thank you very much, and I'll now yield to the Ranking Member.

Mr. GRAYSON. Thank you. I have some questions for Dr. Atwater. I'm going to try to understand better how the research that you're doing fits into the bigger picture of energy production and storage.

What you described as an effort to create solar fuels as opposed to the more typical effort to create electricity from solar power. Is that correct?

Dr. ATWATER. That's right, yeah.

Mr. GRAYSON. All right. So is that similar, would you agree, to something like ethanol production, or is that different?

Dr. ATWATER. Well, so ethanol is an example of a chemical fuel. It's a liquid fuel that's suitable as a liquid fuel, and that is indeed what—ethanol is normally produced by, for example, fermentation of feedstocks from crops and plants and so forth, and that's a process that is established but it's limited by the efficiency of natural photosynthesis. So what artificial photosynthesis or fuels from sunlight as the—in the research objectives at JCAP is focused on the same process of chemical fuel production but with a much higher efficiency. So the efficiency potential for fuel production rivals that of the efficiency potential for photovoltaic systems. For example, if you put solar panels on your rooftop, you can expect that the solar panels will operate with an efficiency for electricity production of something like 20 percent of the total sunlight falling on your rooftop. For example, natural photosynthesis is less than one percent efficient for most plants and photosynthetic organisms. So there's a big gap there. And so JCAP is working to develop processes that can make fuels very selectively. We want to make one fuel, say, ethanol or methanol or hydrogen, and not a bunch of byproducts. Nature does this, of course, very well. But nature's not particular efficient. And so to make an economical source of fuel generation that can generate and foster a new industry focused on efficiency, and like the nuclear Hub, I would mention we're focused on reliability because if you think about the return on investment for any solar panel that you would put on your roof, it has to last for a long time. It has to last for 20 or 30 years in order to get that return on investment. Similarly, we want to make devices that are robust and reliable and that last for a long time.

Mr. GRAYSON. So are you trying to basically do what biology does through only chemical and physical means or are you trying to take biological processes and tweak them and improve them?

Dr. ATWATER. Yeah. In JCAP, we have a very sharply focused research program that's focused on chemical catalytic processes and physical processes for the charge generation. So we're using actually for the source of energy generation semiconductors very much like the semiconductors that are used in solar panels to generate electricity. But the charge carriers are then driven to chemical catalysts, not biological, so we're working on non-biological routes, and as I indicated, we've already been able to achieve efficiencies for hydrogen production that are of the order of ten percent and 10 times greater—more than ten times greater than that for natural photosynthetic processes.

Mr. GRAYSON. So the fuel that you've created so far is hydrogen, not a traditional transportation fuel?

Dr. ATWATER. That's right.

Mr. GRAYSON. Now you're going to try to branch out into something that you could actually put into a car——

Dr. ATWATER. That's right.

Mr. GRAYSON. —these days like octane or ethanol or methanol or something.

Dr. ATWATER. That's right, exactly, so the grand challenge is under mild chemical conditions very much like the way a solar panel would operate, can we generate directly a chemical fuel without having to build another large plant to do the downstream distillation and refinement.

Mr. GRAYSON. One of the more interesting things about solar power production is that there are arguments in favor of large-scale production, arguments in favor of small-scale production. Are you finding any sort of economies of scale that would tilt you toward large-scale production for this purpose, or not?

Dr. ATWATER. So we have done—the best way to answer that is to look at the record of an industry, and we don't have an existing solar field industry. However, JCAP has done some studies of the scalability. So what would it look like and what would be the key drivers for improved efficiency and cost reduction if you were to build, say, a 1-gigawatt-scale plant. That's a very large-scale plant. For example, a conventional power reactor would be of the order of hundreds of megawatts to a gigawatt. And what you see is that the primary drivers of the cost and the economic return are the efficiency and the durability of the solar fuel generator itself. It's not the tanking and the piping and other infrastructure.

So the preliminary analysis shows that, you know, the investments that we're making in the research on the technology advancement itself are key drivers. So to answer your question directly, it looks like there's not a big sensitivity to scale.

Mr. GRAYSON. All right. Last question. Do you have any judgment yourself about the possibility or the prospect of actually taking biological processes that exist and tweaking them, improving them to the point where they can become commercially viable?

Dr. ATWATER. Yeah, that's a very interesting question. The wonderful thing about nature is that it's regenerative, you know, in our bodies and in plants and so forth, cells are regenerated, and the typical photosynthetic organisms only last for, you know, minutes to hours before they die and then nature has the benefit of regeneration. So we've really focused in our effort on non-biological routes because we want to make—because we know that we want to make things that last for tens of years. So JCAP really is focused on chemical and physical processes, which we think, you know, demonstrated by, you know, the record of durability of conventional solar photovoltaic panels that have the prospect of being durable for a very long time without regeneration.

Mr. GRAYSON. Thanks. I yield back.

Chairman WEBER. I thank the gentleman.

I now recognize the gentleman from California. Dana, you're up.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman.

A couple of specific questions, and Mr. Gehin, is that how I pronounce it? Am I correct in that?

Dr. GEHIN. Close. Gehin.

Mr. ROHRABACHER. Okay. I didn't quite get that. A little louder?

Dr. GEHIN. Gehin.

Mr. ROHRABACHER. Gehin. Okay.

Your focus on advanced simulation for light water reactors, we have a light water reactor in Orange County, and it's shut down now, and we have found all over the world where light water reactors have made things—have been put public—the public around those light water reactors in danger, and so now there is a danger associated with every energy source, but don't we have other potential sources of nuclear energy that are less dangerous that what light water reactors will be? And why are we stuck on light water reactors? I mean, I must have been briefed on three or four different alternatives to light water reactors that are safe and will not leave plutonium behind and can't melt down, whether they're pebble-based or thorium or high-temperature gas-cooled reactors. Why are we still putting money into light water reactors rather than going to a new generation of a different concept that wouldn't be dangerous?

Dr. GEHIN. Yeah, so that's a very good question. I think, you know, my response will be, we need to look at both. I mean, we have a large current fleet generating a lot of clean, low-cost energy that the safety record is quite good on. And so CASL's goal is to improve upon that, so—and I think we're doing that as well.

There are other—there are other advanced reactor concepts. DOE is doing research on these with expectations of deployment later on in this century. And so hopefully that will be a possibility. CASL's, though, focus is, we have the existing fleet of 99 reactors. We're going to be adding five more. Let's operate those the best that we can and get all the benefits that we can.

Chairman WEBER. Will the gentleman yield for just a second?

Mr. ROHRABACHER. I certainly will.

Chairman WEBER. I'll give you some extra time.

In somebody's testimony, I read where the nuclear reactors we use on subs are safe because they're designed to shut down in the event of a military incident. Whose—was that yours, Dr. Gehin? Do you remember?

Dr. GEHIN. No, it wasn't me.

Chairman WEBER. Okay. What kind of reactors are those? Are they light water reactors?

Dr. GEHIN. Yeah, that's my understanding, although that's technology that the Navy protects very closely, but, you know, they put a lot of effort in the design of those reactors to ensure that they're safe.

Chairman WEBER. All right. Thank you. Reclaiming your time.

Mr. ROHRABACHER. All right. Thank you.

What we're talking about is research that was done back in the 1940s and 1950s, and light water reactors are old technology. This is like trying to improve the steam engine. I mean, we spent a lot of money improving steam engines, and in fact, I believe light water reactors are based on steam engines.

Mr. Chairman, I would suggest that focusing our limited research dollars on light water reactors is a terrible waste and misuse of limited dollars that we have here. At the very least if we are going to use nuclear energy, let's focus on those very promising technologies that we have not invested in yet rather than trying to perfect something that we've been basically researching for 40 and 50 years. I'm dismayed about this, and I've been talking to the Department of Energy about this for a number of years, and we just can't get them to invest. As I say, there's at least three or four alternatives that I know about, and I'm not a scientist. So with this, let me ask about batteries, Mr. Crabtree.

Again, are we researching old methods of batteries or do we have some new methods? I understand that, I think it's Dr. Goodenough has got some sodium base. I'm not an expert on any of this stuff. Pardon me. You guys know much more about it than I do, but what about Dr. Goodenough's research into sodium batteries and what's your reaction on that?

Mr. CRABTREE. So that's a great question. JCESR looks exclusively beyond lithium ion. Lithium ion is the technology we have now that powers cell phones, although not long enough. They go out at 4 o'clock in the afternoon when you want to make a call.

Mr. ROHRABACHER. Right.

Mr. CRABTREE. And we're looking beyond that. We'd like to get a factor of five in performance and higher and a factor of five lower in cost. So this is definitely next generation.

None of the batteries that we're looking at are related to lithium ion in their concepts or in their performance. So there—many people don't realize this, that beyond lithium ion space is very much better and richer than the lithium ion space. So lithium ion is one battery technology, been around for 25 years nearly. We know it pretty well. It can get incrementally better, but just as you were saying, we're looking for a transformative change, not an incremental change.

Mr. ROHRABACHER. So let me just point out what we're—that was the right answer for nuclear energy, and so thank you very much. I'm glad that you're doing what we expected our Hubs to be doing.

Thank you, Mr. Chairman.

Chairman WEBER. The preceding comment was an editorial statement, not necessarily reflecting the view of the management.

The Chair now recognizes Mr. Lipinski.

Mr. LIPINSKI. Thank you, Mr. Chairman. I'm not sure I can even add anything more. I was going to ask Dr. Crabtree some questions but what more than an endorsement from Dana Rohrabacher could there be? But I'll go ahead anyway.

Battery technology in so many ways we know is critical for a real clean, affordable energy future, and certainly, as Mr. Rohrabacher said, it is a—what's being done at JCESR is certainly what we need to be reaching for. I mean, right now we have Tesla, Google and Apple making investments in energy storage. Tesla announced its giga factory to be completed next year, but we really need to find that breakthrough technology, and I think you did a good job.

My first question was going to be, you know, how the Hub works, it helps towards making a breakthrough but I think you did a very good job of explaining how the Hubs give you the—your Hub gives you the opportunity to be very nimble in what you're doing, so that was a great example of one of the advantages of a Hub.

I want to ask about the connection to industry because I know JCESR has partnered with companies like Dow, Johnson Controls, and Applied Materials. Can you explain how these partnerships help JCESR to span the whole innovation ecosystem and help, you know, look to the future to bring these technologies to the market?

Mr. CRABTREE. Yeah. Great question, and indeed, this was one of the things that when we made our proposal and launched our project that we had in mind. What do you do after you make the technology? How do you get it out to the marketplace? So JCI, otherwise known as Johnson Controls, happens to be right across the state line in Wisconsin from Argonne, so we go up there quite often. We spent three full days talking with them about what a prototype would look like that would interest them in manufacturing it. So this is something that certainly on the basic science side almost never happens. We think about the new ideas in the basic sciences but we don't think about how to bring them to market. On the applied side, it does happen. I think JCESR is unique in that it combines both the basic science discoveries and the guidance from industry, for example, JCI, what would it take to actually be manufactured. So they can advise us, for example, don't use any materials in a certain class, they're too corrosive. We will know that from the very beginning, and at a discovery science stage, we won't be pursuing those kinds of materials. So their guidance is actually very, very important.

We have another group that works with us and our affiliates, which now number 80 plus. They're start-up firms. They're big companies. They're research organizations. And we talk with them all the time about their interest. So the ones that are startups, we talk about what kind of battery would you like to have, and I think it's this connection to the marketplace which is one of the unique things about JCESR that was missing before. So Toyota will look to its own research and development organizations with its own marketing needs in mind but they won't go outside their own house. We make it possible to go outside individual organizations.

Mr. LIPINSKI. So have you seen companies make these connections set up locally to have the access? Does that make a difference?

Mr. CRABTREE. Oh, it does. So we—there are several battery firms, usually small companies, that we work with extensively already. We—this does two things. It makes us familiar with what their needs are so we can address them better, and it makes them familiar with what we can do. So they can address a question or a challenge to us that in fact we can respond to.

So it's spilled out. You know, Argonne has a very extensive traditional battery program, lithium ion and other things, that's not part of JCESR but we interact with that group as well, and when we—through our affiliates and other industrial connections, we actually direct them to the right place. If it's within JCESR, that's great. If it's not, then we're part of that interaction as well.

Mr. LIPINSKI. Thank you. I have a very quick question—I have little time—for Dr. Atwater. I was—it was probably now about 7, eight years ago now, I was at JBEI. So are you working completely—something different than they are?

Dr. ATWATER. Yeah, that's good——

Mr. LIPINSKI. Because—go ahead.

Dr. ATWATER. Thank you for your question, Mr. Lipinski. So we actually have Dr. Jay Keasling, who's the Director of JBEI, as a member of our board of governors and so there's close coupling and communication between JBEI and JCAP. JBEI takes a focus on using alternatives to the traditional biofuels feedstocks to generate a new generation of biofuels. As I was alluding to in my response to Mr. Grayson, JCAP's focus is on using physics and chemistry to achieve the same outcomes as natural photosynthesis using artificial photosynthesis with greater—such that the generator has greater durability and greater efficiency, so that's the primary distinction between the two.

Mr. LIPINSKI. Thank you. I yield back.

Chairman WEBER. The gentleman yields back.

The gentleman from Georgia is recognized.

Mr. LOUDERMILK. Thank you, Mr. Chairman, and Dr. Gehin, I want to circle back over to the light water reactors. I'll take a little different approach here, but in Georgia, Plant Vogtle is bringing online hopefully very soon two Westinghouse AP–1000 reactors. We're actually taking a CODEL trip to visit Georgia Power here next month to view those.

In light of what Mr. Rohrabacher said, can you elaborate a little bit how CASL and VERA have been useful in licensing, ensuring the safety operations of the AP–1000s and should the people in Georgia be concerned or is the technology sound? Can you elaborate a little bit on these two new reactors coming online?

Dr. GEHIN. Yeah, so thank you. It's very exciting to have these two reactors coming online in the South. I'm from the South so it's great to have that more power there.

I also point out, Southern Company is part of our industry council we've got interactions as well with the folks working on that plant as well, Westinghouse, the designer of that plant.

You know, the AP–1000 design has been worked on by Westinghouse and evolved and very rigorously reviewed through, you know, the NRC licensing process, and so it has got a well-founded safety basis. It enhances the safety of our current fleet, incorporates lessons from Fukushima. So I think these are very impressive designs, very safe reactors. So I would not hesitate living near a reactor like that.

As far as CASL, CASL insofar as the timing was not in place to impact the licensing. AP–1000 received its design certification several years ago, and the construction operating license was in place several years ago. But what we are doing working with our Westinghouse partner, applying our tools so they can actually use these to compare to and confirm their own results and help improve their tools for future operations and when those reactors start up so they have more information. So we expect there will be usefulness from our tools going forward but they've not played a direct role in the current licensing of those reactors.

Mr. LOUDERMILK. With reactors such as the AP–1000, we're bringing these on, they're the first new reactors we've brought on in how many years?

Dr. GEHIN. So Watts Bar One came online in 1996. Watts Bar Two which was started, you know, a couple decades ago will be online next year, and so these will be the second reactor online in this century in the United States.

Mr. LOUDERMILK. Are there obstacles that are in the way of expanding nuclear power in the nation that this body can work on?

Dr. GEHIN. You know, so one of the areas that we're focused on helping, and it's broader than just CASL, is the economics of nuclear power. It does provide low-cost economics but in competitive markets with variations, it can be rather difficult. You know, it's not a—it has a technical aspect that we're working on to reduce the operating costs, fuel costs. There are other non-technical areas as well that probably need to be addressed. This works very well in the South where there's a regulated electricity market where you can plan long-term, so that's why you're seeing these built in the South. I think continue to improve the economics, improve the benefits that we're getting from it but also looking at some of these non-technical issues might be worthwhile.

Mr. LOUDERMILK. And one last question back on something that Mr. Rohrabacher brought up is other plants that had safety concerns. Can you elaborate on what were those, why were those plants shut down, and why is Plant Vogtle different?

Dr. GEHIN. Yeah, you know, as far as I know, you know, there are some plants that have been shut down in the United States. I don't—I wouldn't attribute necessarily that shutdown to safety concerns. There have been issues that have resulted in economic evaluation to not, you know, address like replace stream generators or address steam generator issues. When you do the economic analysis, you find out, you know, the business decision is not to do that. These could be addressed. They could have been brought back but the economic decision was not to do so.

Mr. LOUDERMILK. Thank you, Mr. Chairman. I yield back.

Chairman WEBER. Thank you. The gentleman from Colorado is recognized.

Mr. PERLMUTTER. Thanks, Mr. Chair, and I want to thank the panelists for being here today. This is fascinating. And I'm going to ask more general questions, not as specific as some of my colleagues have asked.

And Dr. King, I'd like to start with you. The purpose of these Hubs in my estimation, and as policymakers, we're trying to decide are they working, are they not working, are they doing the kinds of things that you might expect as an experienced scientist and an administrator. Do you see these Hubs as beneficial to the future of this country? And it's going to be that broad, so go for it.

Mr. KING. Short answer, yes.

Mr. PERLMUTTER. Okay. Why?

Mr. KING. Because among many things the Hubs can do is, they bring an intense focus on a particular technology or scientific challenge, and they put resources in the hands of scientific leaders who are able to, as I said in my earlier remarks, orchestrate the immense talent and tools that we have around the country to actually solve problems in very much shorter order in time than has typically been the case. So in the case of CMI, we've achieved in two years what typically takes 20 in a few well-selected cases. I'm not saying we can always do it.

Mr. PERLMUTTER. Well, but that's the nature of science too.

Mr. KING. Yes.

Mr. PERLMUTTER. I mean, if there weren't some errors to go with the trial and errors, you wouldn't be learning much. If you knew the answer before you started, then, you know, what's the point. So——

Mr. KING. I agree completely.

Mr. PERLMUTTER. So I appreciate that.

So Dr. Crabtree, my question to you is, how do you determine what the question is, what the mission is, and how do you put the team together?

Mr. CRABTREE. Great questions, and that's exactly what JCESR faces. I was mentioning that the beyond lithium ion space is really rich, big and complex, and there's really a challenge to find out where are the promising directions. So we spent about a year and a half doing that. We call that divergent research because maybe it's the solution, maybe it's that one, maybe it's that one. We've now switched in the last year to convergent research where we've picked four directions and we're going to implement them and make them work. But I'm sure that we're going to leave things on the table. So there will be things, even when we're done, assuming we get renewed—let's be optimistic—you know, eight years from now, there will still be wonderful challenges to be addressed in a similar way.

Mr. PERLMUTTER. How did you put your team together? How did you determine which industry partners, which academic institutions would be part of your Hub?

Mr. CRABTREE. Great question. So the first requirement is they have to be good. They have to be the best. If we can get the best, we go for the best. If we can't, we go down a notch. And we have to be diverse. So we want to be able to look at the entire beyond lithium ion space, not just a piece of it, but all of it so that we can make a judgment about where are the best opportunities. And so we have universities, national labs and industry, and that's critical that it be that diverse.

Mr. PERLMUTTER. I mean, if I raised my hand and I said gee, Doctor, I'd like to be part of your team, how do you vet me? I mean, I'm just a lawyer so I wouldn't add much other than I'd try to keep you out of trouble.

Mr. CRABTREE. We have lots of lawyers on the team too.

Mr. PERLMUTTER. All right. Good.

Mr. CRABTREE. First we would ask, is it covered by somebody that we already have or is there somebody better than you—excuse me for asking that question, but—because we want to go for the best, and we don't want to duplicate. Our resources are limited so we have to spread them around just as taxpayer dollars, you always do, in the best way. So we don't want to duplicate and we want to cover everything.

Mr. PERLMUTTER. So Dr. Gehin, how long should these Hubs remain in operation? Is it in perpetuity or is there a finite time period? What do you expect as the administrator of your Hub?

Dr. GEHIN. So we're expecting, and we've already done this to some degree, of having capabilities that we're deploying to industry for their use in the short term. We've done that in the first five years. We will continue to do that with our renewal.

With that said, there are—these technologies require sustainability. We're looking to that as far as through our industry partners and other means of maintaining something that we develop so we don't lose it as soon as the Hub ends. We're looking towards industry to do that because they're the ones who will take this technology forward.

Means of performing additional research is uncertain at this time. I think we'll learn things that will lead to additional questions and insights that could be carried forward but our current approach is within the ten years have expanded simulation capabilities that we can hand off and have those be applied in a reactor operation.

Mr. PERLMUTTER. Okay. And my time's up. I'll get to you, Dr. Atwater, next go-around, okay? I yield back.

Chairman WEBER. Would the gentleman like an additional minute?

Mr. PERLMUTTER. No, no, go ahead, because I've got to go downstairs and ask questions——

Chairman WEBER. Because I was going to take it from the gentlelady from Massachusetts.

The gentlelady from Massachusetts is recognized.

Ms. CLARK. Thank you, Mr. Chairman, and thank you to all the panelists.

I have—I also have a sort of general question for all of you, but it's been a theme that's come up. Dr. Crabtree, you referred to it. This—we tend to talk about basic and applied research in two different buckets and, you know, really silo that, and I think it has an impact in not only how we look at science and the way the Hubs are working but also in other areas in the way we fund things and prioritize. What I'm hearing from your testimony—and we had a hearing last month where Dr. Whittaker also referenced that this is sort of a false dichotomy that we have put together, and I would love to hear in your experience in the Hubs how you see this and, you know, do you see any potential dangers in really looking at these as two very different siloed ways of looking at science and research?

Mr. CRABTREE. Great question, and I would hark back to maybe 25 years ago, the time of the great industrial labs such as Bell Labs and Xerox and IBM where they were integrated and indeed the basic science was done right along with the application development. We've lost that, and part of that is the pressure of Wall Street. Business has to look at the next 6 months, not the next 20 years. That's hard.

JCESR is one of the few organizations, brand-new one, that bridges that gap and it looks at a very specific problem unlike the old industrial labs that looked at many, many problems. We're looking at next-generation energy storage only. So we're able to focus, we're able to bring—attract the best, and we're able to integrate across that spectrum, and I believe that this paradigm, this, as we call it, our next paradigm of doing business, doing research, may be the most important outcome of JCESR, that it may be a model for not only the battery community but lots of other critical challenges where you combine the basic and the applied and actually the transition to market. So I'm actually excited about that, and I feel that we're learning now how to do it. It can be done much better than we are now doing. I'm sure of that, and if we can develop this model, we'll be way ahead of the game.

Ms. CLARK. And one of my concerns is that as we look at innovation as a pipeline, if we don't start using the model that you are using, you know, where are we going to be as we pull back? And I don't know if any of the other of you have concerns or want to comment on that. Dr. Atwater?

Dr. ATWATER. Yeah, let me just respond to your comment, and thanks very much for your insightful question. So JCAP I would say has—if you think about spanning the spectrum from fundamental research to deployment and development and scale-up sort of furthest upstream and has activities that start on the basic research but do in fact span all the way through applied research, and we provide the insights that create the deployment decisions that have yet to be made as we operate in an environment where there is no existing industry.

But I did want to say that the progress that we've made in defining just the basic question of what does a solar fuel generator look like. We have a now well-defined model concept of what a generator is. It has a cathode and an anode, very much like a fuel cell or a battery. It has an electrolyte. It has various components that five years ago before an integrated team of scientists and engineers came together from across the applied and basic research spectrum really didn't exist, and it's that collective synthesis of ideas and then execution of potential prototypes that led to the concepts of the solar fuels generator. So while we don't address through applied research and development yet an existing industry, the acceleration of progress that we've made actually depended on the interaction with applied researchers as well.

Ms. CLARK. Great. Dr. King?

Mr. KING. Yeah, I think the old model is fading. We certainly work with a lot of researchers who have spent their career working in fundamental research and publish a paper and worry not about how it will be commercialized. We started the process where every time we take on a fundamental research topic, we have industrial potential users come in and talk with the researchers about it. But first we were desperately worried that this would not work. What we have found is two things. One is that the academic and national lab researchers actually enjoy it very much indeed. They come out of the room saying why didn't we do this 20 years ago, and the research has accelerated considerably. Case in point: We are trying to develop new red and green emitting compounds, used very fundamental physics and computer models in a materials genome type of campaign, came up with a dozen different compounds that could emit green light and presented those instead of just publishing those and then going on to work on producing all 12, testing them, refining them, et cetera. We went to our industry partner, and our industry partner looked at the 12 compounds and said only three of those would ever be considered in our company, and they gave different reasons for rejecting the other nine. When you think that testing 12 pounds is typically a 20-year campaign, we have just saved 15 years of research. So getting constant feedback from industry is enriching, enlivening, and it's inspiring to the researchers but it's also a huge accelerator for the research itself.

Ms. CLARK. Great. Thank you.

Chairman WEBER. The gentlelady yields back. Ranking Member Grayson would like to ask at least one more question, so we're going to give him time to do that.

Mr. GRAYSON. Thank you, Mr. Chairman.

Dr. Gehin, we have something like 300-plus light water reactors in the world. They're very expensive, something like half a trillion dollars in replacement value for those reactors. In the United States at least, energy production facilities are privately owned. I have to wonder, as much as I'd like to see the advancement of human knowledge in general, why is the industry not trying to add 20 years of life to a half-a-trillion-dollar asset? Why does this fall upon the taxpayers to do this?

Dr. GEHIN. You know, so the—so that's a very good question. So I think industry is very interested in this. I think where the value comes in with the government-sponsored research is enabling this through the tools that we've already invested in advanced computing, the leadership-class computing capability that we have, the fundamental science, speaking to Ms. Clark's question, taking some of the basic technology we have and improving that national investment into our reactor systems. So I think it adds value to things that they're already motivated and doing that they wouldn't otherwise do or have access to.

Mr. GRAYSON. Are they doing it? Are there private research facilities that actually are trying to do what you're trying to do and making any progress?

Dr. GEHIN. Not at the scale that we're doing it with the science that we're using.

Mr. GRAYSON. Is the industry willing to come together and try to fund those facilities since it's for their benefit?

Dr. GEHIN. Well, they already are, so one thing that's important to understand about the Hub is, or at least Hub, is that the industry partners cost share. So they're already making investments into the Hub through cost sharing and data that we could otherwise have access to.

Mr. GRAYSON. I yield back. Thank you.

Chairman WEBER. Okay. I want to thank the witnesses for their valuable testimony and the Members for their questions. The record will remain open for two weeks for additional comments and written questions from the members.

This hearing is adjourned.

[Whereupon, at 11:57 a.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Alex King

Representative Eric Swalwell
House Science Subcommittee on Energy
2318 Rayburn House Office Building
June 17, 2015; 10:30 AM

Questions for Hearing -*Department of Energy Oversight: Energy Innovation Hubs*

Dr. Alex King, Director, Critical Materials Institute (CMI)

1. Dr. King, I recently reintroduced H.R. 2687, the *Security Energy Critical Elements and American Jobs Act.* My bill would authorize a research and development program at the Department of Energy (DOE) in energy critical elements. These are elements crucial to advanced energy technology. To carry out this program, an energy hub- such as the Critical Materials Institute hub you direct - is also authorized.

   Does H.R. 2687 reflect and provide support for the activities of the Critical Materials Institute (CMI)?

H.R. 2687 accurately describes the current activities of the Critical Materials Institute.

2. Dr. King, I assume you feel the work done at the CMI is important, correct? If so, why? Why is it so important we diversify supply, develop substitutes, and maximize efficiency when it comes to energy critical elements?

Naturally, I agree that CMI's work is important. As noted in a recent commentary from McKinsey & Co., renewable energy sector stocks have outperformed most other market sectors, gaining more than 17% in 2014[1]. McKinsey goes on to opine that "*In short, a world powered by renewables is not around the corner. This will be a long-term transition—a matter of decades, not years. But the resiliency of the sector in the face of much lower oil and gas prices is a sign that it may just be on its way.*" If this analysis is correct, then the manufacturing of clean energy technologies such as wind and solar electrical generation, the necessary energy storage capacity to support these, and efficient energy consuming devices such as LED lights and electric vehicles, will be a major source of investment opportunities and new jobs in the coming decades. The realization of this manufacturing growth, however, depends on the availability of materials such as neodymium and dysprosium, used for motors and generators, lithium, used for batteries, and europium, terbium and yttrium, used for efficient lighting. All of these materials are classified as "critical" for these technologies, meaning that they have fragile supply chains, subject to disruption from a number of different sources. The task for CMI is to reduce the risk of such disruptions, and thereby reduce risks to investments in clean energy technologies and other sectors that use the same materials.

3. Calling them "functionally essential and presently irreplaceable," Dr. King, in your

1 http://www.mckinsey.com/insights/energy_resources_materials/lower_oil_prices_but_more_renewables_whats_going_on

prepared statement you note how important rare earth elements are for "modern weapons systems." Can you expand on that? Which weapons systems need these elements, and in what ways?

Given their ubiquity in today's technologies, it is actually hard to imagine that *any* weapons system is free of rare earth materials. Rare earth elements are found in all land, sea, air and space vehicles, all computer hard disk drives, all displays (including those in night-vision systems), all microphones, headsets, and almost all loudspeakers. They are essential for the GPS system. Any system that contains a magnet, an electric motor, a generator, a microphone or a loudspeaker, and many actuators, makes use of neodymium and many also require dysprosium. Any system that includes a display or a fluorescent or an LED light makes use of europium, terbium, yttrium, or other critical elements. The vast majority of recyclable batteries require either lithium (for lithium ion batteries) or rare earths (for nickel metal hydride batteries).

For a few specific cases, I refer you to the Chairman's Mark for the FY14 Defense Authorization Bill, where it was noted that: *"... the report on the feasibility and desirability of recycling, recovery, and reprocessing of rare earth elements required by the conference report (H. Rept. 112-329) to accompany the National Defense Authorization Act for Fiscal Year 2012, states that each SSN-774 Virginia-class submarine would require approximately 9,200 pounds of rare earth materials, each DDG-51 Aegis destroyer would require approximately 5,200 pounds of these materials, and each F-35 Lightning II aircraft would require approximately 920 pounds of these materials.[2]"*

4. Dr. King, in your prepared testimony you argue that the successes of the CMI so far "have strong potential for providing returns to the U.S. taxpayer." What do you mean by this? Can you quantify it?

CMI made 35 inventions and submitted 5 patent applications in its first two years of operation. Many of these have attracted interest from corporations who are investigating the possibility of obtaining licenses to use the technologies. Under the provisions of the Bayh-Dole Act (1980), the Stevenson-Wydler Act (1986), and the America Invents Act (2011), a portion of any licensing income is returned to the inventor(s), a portion to the inventing institution and (potentially) a portion to the U.S. Treasury. The portion returned to the inventing institution is used in support of science, education and technology transfer at the institution. It is difficult to assess the potential value of any of these licenses at this point, but one Ames Laboratory patent, issued to the Iowa State University for the invention of a material (prior to the existence of CMI), generated $59 Million in royalties, of which $5.8 Million was returned to the U.S. Treasury.

5. Dr. King, you noted that CMI brings together the public and private sectors. Which corporations are most involved in CMI?

Our research program is dynamic, so the involvement of any particular corporation varies over time, but GE has been consistently engaged with CMI at a high level, working on projects to provide alternative materials for certain technologies, improved materials for others, and recycling methods appropriate to certain widely-used manufacturing processes. Eck Industries,

[2] http://docs.house.gov/meetings/AS/AS00/20130605/100884/BILLS-113HR1960ih.pdf

a small business, is very actively engaged with us at this time, working on the development of a new alloy for automotive applications. OLI Systems, Inc. is a small company that is significantly focused on CMI's efforts in developing databases of thermodynamic information in support of many of its R&D programs.

CMI's formal arrangements with corporations come in two "flavors":

Team Members take an active role in our research efforts. They are:

- Advanced Recovery, Inc., Newark, NJ (Small Business)
- Cytec Industries, Inc., Woodland, NJ (Large Business)
- Eck Industries, Manitowoc, WI (Small Business)
- General Electric Global Research Center, Schenectady, NY (Large Business)
- Molycorp, Greenwood Village, CO (Large Business)
- OLI Systems, Inc., Cedar Knolls, NJ (Small Business)
- Simbol Materials, Pleasanton, CA (Small Business)
- United Technologies Research Center, East Hartford, CT (Large Business)

Corporate Affiliates provide industrial viewpoints and share information with CMI. They are:

- ASTM International, W. Conshohocken, PA (Non-profit)
- Etrema Products, Ames, IA (Small Business)
- Infinium Natick, MA (Start-up)
- Montana Tech University, Butte, MT (University)
- Nanofoundry Glen Allen, VA (Start-up)
- Native American Mining Solutions, LLC, Kennewick, WA (Start-up)
- Phinix, LLC Lexington, KY (Start-up)
- PrintSpace, Rexburg, ID (Start-up)
- Rare Element Resources, Lakewood, CO (Small Business)
- Tasman Metals, LLC, Vancouver, BC (Small Business)

We are also in discussions with a number of additional corporations concerning engagement with CMI in a number of different modes.

a. You also describe CMI as integrated across basic and applied research. Why isn't this the kind of approach an individual private company would take? Is there no short term profit?

Corporate research and development is typically focused more on applied research than basic research. State-of-the-art basic research skills, and tools such as synchrotron light sources or supercomputers with advanced software are beyond the means of most corporations, especially when they would only be applied from time to time within any single company. CMI's approach is to build teams that allow industry's applied researchers to guide basic research and obtain valuable information by accessing the resources of the nation's universities and national labs. For example, we are assisting our mining industry partners to improve the yield of their froth flotation processes through the use of advanced surface scattering synchrotron x-ray diffraction at Argonne National Laboratory's Advanced Light Source, software development at the Ames Laboratory, and supercomputer calculations carried out at Oak Ridge National Lab. There is no mining company in the world that can sustain basic research facilities and expertise of these kinds, but in this case they are being used to solve an applied problem that has the potential to make a significant economic impact, by improving mining yields as much as 15%.

6. Dr. King, do you think CMI *replaces* or *augments* work done in the private sector? Why?

CMI does not *replace* any work that could be done by the private sector alone. As noted above, we bring resources together, across the basic-to-applied spectrum, to solve applied problems that could not otherwise be tackled by an individual organization.

Our goal is not so much to *augment* work being done in the private sector as to *transform* it through the development and application of advanced basic science tools and concepts and to respond quickly to help mitigate materials criticality.

Appendix II

Additional Material for the Record

STATEMENT SUBMITTED BY FULL COMMITTEE CHAIRMAN
LAMAR S. SMITH

Today, the Subcommittee on Energy will examine the Department of Energy's (DOE) Energy Innovation Hubs and provide important oversight for the Department's approach to collaborative research and development.

DOE Energy Innovation Hubs encourage cooperation across basic science, applied energy, and engineering research and development programs. The hubs represent a new model for integrating basic research and development with applied research to create new technologies.

Through the hubs, DOE brings together teams of researchers from the national labs, academia, and industry to solve specific energy challenges.

Currently, the Department operates four hubs—two with a focus on applied energy challenges and two using basic research to advance technology development.

The Department first established the innovation hub model within its Office of Nuclear Energy in 2010 with the establishment of the Consortium for Advanced Simulation of Light Water Reactors, or CASL [CASTLE]. CASL's diverse team of experts in reactor physics and materials sciences use super computers to model and simulate nuclear reactors.

This work will help make reactors safer, improve their performance, and increase their operational lifetime, which is critical to sustainable zero-emission nuclear energy in our country.

Funded through the Office of Energy Efficiency and Renewable Energy, the Critical Materials Institute was established in 2011 to address domestic shortages of rare earth metals and other materials critical for American energy security.

Led by the Ames National Lab, a leading center for materials science and technology, researchers work to solve critical materials challenges. These include the development of new material sources, the increase in efficiency in manufacturing, and better methods to recycle and reuse materials.

The Office of Science sponsors two hubs that focus on basic research directed at how energy is produced from sunlight and ways to advance battery storage.

The Joint Center for Artificial Photosynthesis, led by the California Institute of Technology, conducts basic research with the goal of designing efficient energy conversion technology that can generate fuels directly from sunlight, water, and carbon dioxide. This research presents the opportunity to recreate the energy potential of natural photosynthesis.

The research and development conducted at the Joint Center for Energy Storage Research hub, commonly known as JCESR [Jay-Caesar] and led by Argonne National Lab, develops new battery storage technology. Researchers at JCESR study how different materials perform at the atomic and molecular level inside a battery.

By examining materials, these researchers are able to develop batteries that have more capacity, power, and a longer-life span.This energy storage research could have groundbreaking impacts on not just the solar industry, but also on all forms of energy and on the reliability of our electric grid.

As DOE pursues new ways to conduct research and development, benchmarks to measure progress and the responsible use of American taxpayer dollars must be a top priority.

With a price tag of approximately $90 million per year for the existing DOE hubs, Congress should conduct appropriate oversight to ensure that limited research dollars are well-spent.

I thank our witnesses today for testifying on their important research. And I look forward to a productive discussion on the research goals of the four DOE hubs.

I also want to thank the ranking member of this subcommittee, Rep. Grayson, for working with me to include targeted authorization language for the hubs in the America COMPETES Reauthorization Act of 2015, which passed the House last month.

The Department of Energy should prioritize the ongoing cooperation between the national labs and academia in order to solve basic scientific challenges. It should also partner with American entrepreneurs to solve energy challenges through new technologies.

Leveraging limited resources through partnerships will keep America at the forefront of cutting-edge science.

STATEMENT SUBMITTED BY FULL COMMITTEE RANKING MEMBER EDDIE BERNICE JOHNSON

Thank you, Chairman Weber for holding this hearing, and thank you to the witnesses for being here today.

First established in 2010, the Energy Innovation Hubs are modeled on legendary research institutions like Bell Laboratories, which unfortunately no longer exist to any great extent in the private sector due to an increased emphasis on shorter-term returns. Each of these large multiinvestigator, multi-disciplinary Hubs is focused on addressing major challenges to advancing new energy technologies. In short, these centers of excellence are tackling a variety of areas that may well be vital to our clean energy future.

They include: dramatically reducing the costs for new energy storage technologies; advanced computer modeling to improve the safety and efficiency of nuclear reactors; addressing our limited supply of critical materials that are essential to a wide range of clean energy technologies; and learning from the world of plant biology so that we can find new, far more efficient ways to create a usable fuel from three simple ingredients—sunlight, water, and carbon dioxide.

I believe it is long past time for Congress to authorize and provide legislative guidance for the Hubs model—which is why I included language to do this as part of the America Competes Reauthorization Act of 2014, and again in 2015, both of which were cosponsored by every Democratic Member of the Committee. I particularly appreciate Ranking Member Grayson's good work in introducing and advancing a bill to finally authorize the Hubs this year.

I want to thank all of you again for being here today. Your work in these key technology areas is a clear example of why we need to not just sustain, but significantly increase federal investments in research across the board, and not just in research areas that have partisan support.

If the past is any guide, these investments in fundamental and applied research, including energy efficiency, renewable energy, and yes, even social and behavioral sciences, will have a major impact on both our nation's economic competitiveness and our quality of life.

With that, I yield back the balance of my time.

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