Written Statement of

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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.