Statement of

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Good morning Mr. Chairman, Ranking Member Frelinghuysen, and Members of the Subcommittee. Thank you for the opportunity to testify today on behalf of the Advanced Research Projects Agency-Energy (ARPA-E). As the first Director of ARPA-E, I am also grateful for the opportunity to create an organization within the Department of Energy (DOE) with the following mandate:

1. To bring a freshness, excitement, and sense of mission to energy R&D that will attract the U.S.'s best and brightest minds—those of experienced scientists and engineers, and, especially, those of students and young researchers, including those from the entrepreneurial world;
2. To focus on transformational energy research that industry by itself cannot or will not support due to its high risk but where success would provide dramatic benefits for the nation;
3. To utilize DARPA-like organization that is flat, nimble, and sparse, capable of sustaining for long periods of time those programs whose promise remains real, while phasing out programs that do not prove to be as promising as anticipated; and
4. To create a new tool to bridge the gap between basic energy research and development/industrial innovation.

ARPA-E's mission is to:

1. Reduce energy imports and improve energy efficiency
2. Reduce energy-related emissions, especially greenhouse gases;
3. Ensure U.S. technological lead in developing and deploying advanced energy technologies.

We have recruited some of the best and brightest from the technical community to form a small team at ARPA-E, and it has been incredibly exciting for me and my team to create this new organization. Prior to my current job, I was a Professor of Mechanical Engineering and Materials Science and Engineering for 13 years at the University of California, Berkeley, as well as a scientist and the Associate Laboratory Director for Energy and Environment at the Lawrence Berkeley National Laboratory. I have been involved in R&D for the last 25 years and am an elected member of the National Academy of Engineering.

I appear before you today to provide an overview of the President's Fiscal Year 2011 budget request of $299.996 million for ARPA-E, explain how we plan to operate in the future, and provide a report of how we have done so far.

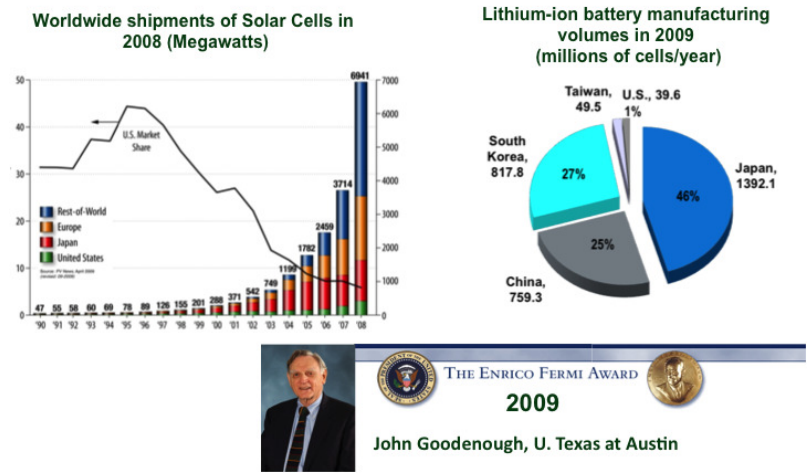

Figure 1. (Left) Global comparison of solar cell shipments. Source: PV News, April 2009. (Right) Global distribution of manufacturing volume of Lithium-ion batteries in 2009 (pre-ARRA funding). John Goodenough was awarded the Enrico Fermi Award, DOE's highest award, for inventing the modern Li-ion battery.

Introduction

We are living through the "Sputnik moment" of our generation. Our dependence on fossil fuels threatens our energy and environmental security and we must step up our clean energy efforts. Business as usual is not a viable option. Conversely, taking swift action on energy is a tremendous economic opportunity to lead in what Secretary Chu has called another industrial revolution. We as a

nation need to change course with fierce urgency.

To illustrate this point, I have included two snapshots of production that are key to future energy use. Figure 1 (above) shows the trends in US market share and shipments of photovoltaic solar cells. In a span of 15 years, the US market share has decreased from 45 percent to less than 10 percent. It is worth noting that the modern solar cell was invented at Bell Labs, a US company. Figure 1 also shows that the US had one percent of the manufacturing volumes of Lithium-ion batteries in 2009 (pre-American Recovery and Reinvestment Act of 2009 investments). It is also worth noting, and ironic, that the modern Lithium-ion battery, like the modern solar cell, was also invented in the US, and Professor John Goodenough received the 2009 Enrico Fermi award from the DOE for doing so.

ARPA-E was created to accelerate the pace of innovation in energy technologies. The projects it supports are to have a high impact on its mission and would lead to new and game-changing global business opportunities. Given the magnitude of the challenge and opportunity and the investments in clean energy overseas, the next few decades have to be the most innovative period of our history.

Where we are now

The National Academies released a 2005 report, "Rising Above the Gathering Storm," that included the recommendation to establish an Advanced Research Projects Agency—Energy within the DOE. In August of 2007, Congress passed the America COMPETES Act which authorized the program. President Barack Obama announced the launch of ARPA-E on April 27, 2009, as part of a sweeping announcement about federal investment in research and development and science education. The Recovery Act provided $400 million in funding for ARPA-E.

Now that the first tranche of those funds have been awarded, I would like to provide a report of where we are today. The first funding opportunity announcement (FOA) was open to all energy technologies. It received an overwhelming response from the technical community – 3,700 concept papers, 340 full applications, and, after a thorough review process, 37 projects were selected. Each award averaged $4 million over a project life of two to three years for a total of $151 million in selections. These projects were selected based on the impact on ARPA-E's mission, innovative technical approaches, superb teams, opportunities for the US to gain leadership and to pursue technologies that are underserved by other parts of DOE and the private sector. If successful, these technologies could be game-changing and launch new opportunities for American businesses and jobs.

While the first FOA round was a clear success, the large oversubscription meant there were many innovative ideas that we could not support with current funding. We invited back many diverse teams we did not fund to ARPA-E workshops where we brainstorm on the most promising opportunities for high impact program areas and optimal program structures, and we base many of our forthcoming funding opportunities on these. Learning from the first FOA round about topics that showed significant depth of innovations, a series of workshops focused on specific topics such as energy storage and carbon capture. The second FOA round was announced Dec 7, 2009 for $100 million and selected projects are expected to be announced in early May 2010. This FOA round also drew on lessons from workshops and is focused on advanced batteries for transportation (BEEST), new materials and processes for carbon capture (IMPACCT), and new ways of generating transportation fuels from hydrogen, carbon dioxide, and electricity (Electrofuels). To date, these three programs have received a total of 500 concept papers. While it suggests significant oversubscription given the focused nature of these programs, it also shows that the scientific community is ready to take up the challenge for addressing some aggressive performance and cost targets identified in these programs. The selected projects from the third FOA round, issued March 2, 2010 for $100 million are expected to be announced in early July 2010. The third

round is focused on energy efficient cooling technologies for buildings (BEETIT), grid-scale electricity storage (GRIDS), and devices/systems for power electronics with applications spanning integrating renewable power to the grid at low cost, efficient lighting in buildings, power management in hybrid-electric automobiles, and power management in computing devices (ADEPT).

The goals of the funding opportunities are (a) to either identify technologies that will leapfrog over today's approaches or to create technologies where none currently exist, (b) to focus on identifying projects that are too risky for the private sector to invest in, and (c) to invest in multiple competitive approaches to reach the same goals. We do not expect all the selected projects to work, but we expect at least a few of them to be game-changing. Furthermore, we expect the private sector to pick up these technologies where we leave off and scale them to create new business opportunities.

ARPA-E Energy Innovation Summit

ARPA-E planned and organized—in a span of two months—the first Energy Innovation Summit held in Washington, DC from March 1-3, 2010. The goal of the Summit was to attract our nation's best energy innovators from business, academia, and government to help begin building the next Industrial Revolution in clean energy technologies. The response was overwhelming. We had almost 1,700 registered participants spanning all stakeholder communities, many of which do not often come together. These include: scientists and engineers, entrepreneurs, small and large business CEOs and CTOs, technology investors from the venture community and investment banks, policy researchers and NGOs,. The technology showcase at the Summit displayed and provided demonstrations for the most novel and innovative energy technologies. We invited not only the technologies that ARPA-E funded in the first FOA round, but also those that we could not fund and gave those applicants the opportunity to showcase their technologies to other investors. We have been told that many financial deals were made.

The Summit also brought together as speakers and panelists an incredible lineup of energy thought leaders from around the country to address some of the most challenging issues and biggest opportunities for our nation. The highlight of these included Jeff Immelt, CEO of GE; John Doerr and Vinod Khosla from the venture investment community; Norm Augustine former Chairman and CEO of Lockheed Martin; Senators Alexander and Bingaman, and Congressman Gordon; as well as Secretary Chu. and senior leadership from DOE and the White House.

The Summit provided an opportunity for us to define ARPA-E as a catalyst for change which focuses on technological innovations that could produce potentially game-changing business opportunities. The Summit also provided a forum for the stakeholders to come together and engage regarding ways to innovate our future with fierce urgency. The initial feedback from Summit attendees has been very positive. Not only were people excited to learn about ARPA-E but also to see that ARPA-E enables and promotes a diverse innovation ecosystem to come together and interact. We are starting to plan the Summit of 2011 (with a much longer lead time), and we hope you will join us next year.

2011 Programs – Process and Potential Topics

The President's Fiscal Year 2011 budget request for ARPA-E includes $273.4 million for ARPA-E Projects. The ARPA-E Projects program provides funding and commercialization support to research and development programs at the intersection of applied sciences and integrated energy systems. ARPA-E has created a matrix-based organization structure. On one hand is the Applied Science and Technology Office or the "Technology Push" Office which will invest in platform technologies that can be integrated into various energy systems. On the other hand is the Integrated Energy Systems Office or "Technology Pull" Office, which will invest in the integration of these technologies into smart, energy efficient, and cost-effective energy systems that will have direct market impact. This matrix structure

will maximize ARPA-E's resources and prevent organizational stove piping that could hinder innovation and stifle creative problem solving. See Fig. 3.

The planned program topic areas are (see Fig. 3)

- Decision Science/Buildings;
- Materials/Industrial Power;
- Thermal/Industrial Power;
- Information Science/Transmission;
- Materials/Renewables;
- Biological Chemical/Renewables;
- Thermal/Water & Agriculture; and
- Biological Chemical /Water & Agriculture.

To define the specific role of ARPA-E within these program topic areas, we will hold technical workshops. The results of these workshops will allow us to hone in on the specific technologies that ARPA-E will focus on through FOAs. We plan to hold several workshops to hone in on the FOA topic that will be based on the (a) concept papers and applications received from the prior FOAs, (b) the input received from the Requests for Information (RFIs), (c) input received from the six workshops that we have already held, and (d) the outreach and coordination with DOE applied and basic science offices. These workshops will provide community input about the current state of the art and technical stretch goals the community can possibly achieve in the next two to three years. The workshops also enable people from diverse disciplines to come together and promote teaming.

It should be noted that the output of the workshops could in some cases lead to multiple FOAs if there are distinct technologies that need ARPA-E's focus. Furthermore, ARPA-E may decide not to issue a FOA on some of these topics if it does not fit the ARPA-E mission.

In FY 2011 ARPA-E requests $35 million for the Materials/Industrial Power program topic area and $30 million for each other program topic area above. ARPA-E plansto invest in these areas for a maximum of three years. Each program will consist of multiple projects (between 10 to 15 projects) that will be selected based on the criteria shown in Figure 2. Within each program, the projects will pursue multiple technologies that either compete with each other to reach the same goals, or complement/leverage each other to form an ecosystem. In addition, ARPA-E requests $20.7 million for Seedlings, to provide funding for innovative projects that happen to fall outside the boundaries of the specific focus topic area FOAs.

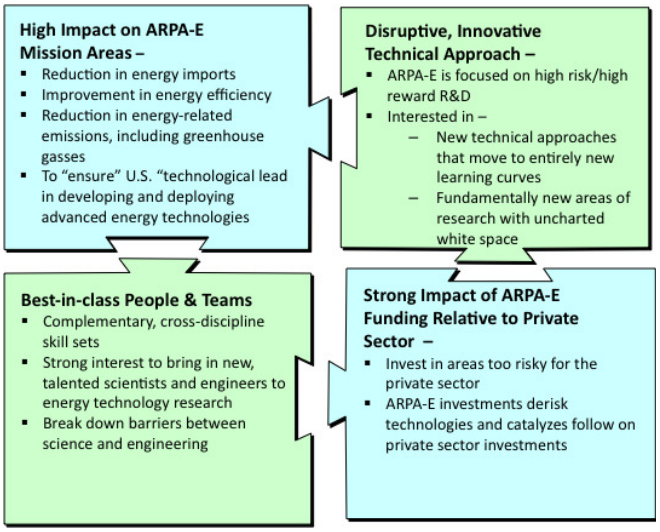

Figure 2 Selection criteria for projects.

Each project will be closely monitored by the respective program director. If a project is not meeting its potential, we may either help the

team take a different direction to succeed, or terminate the project and reallocate the funding to those projects within that program that show promise.

Process of Program Creation: I would now like to explain the process of how we are creating ARPA-E technical programs. It is based on three basic principles:

1. Break down stovepipes between disciplines and remove artificial barriers between basic and applied R&D;
2. Encourage debate and partnership between technology pushers and pullers who will coordinate and leverage other parts of DOE; and
3. Provide thought leadership to create new programs.

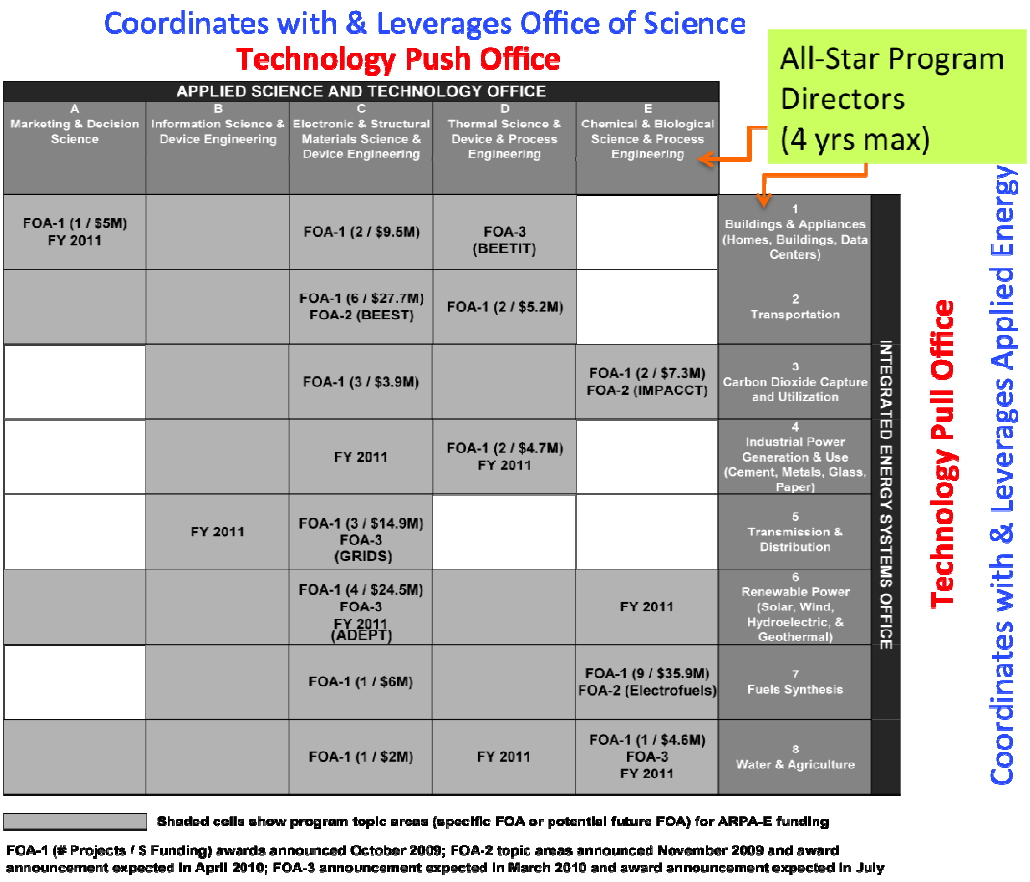

Figure 3. ARPA-E's Matrix Organization Structure that involves coordination and leveraging with other parts of DOE and program creation at the intersection of technology push and pull.

Figure 3 illustrates how these principles will continue to be executed through the following process:

1. Recruit the best and the brightest program directors from the technical community for a maximum of four years. These are people who have one foot in science and engineering, and the other in technology development and business.
2. The program directors will be involved in one of two offices – the technology push office and the technology pull office.

   a. The technology push office will coordinate and leverage the DOE Office of Science and the whole scientific community to identify discoveries and inventions in science that could transform the energy technology landscape via new devices and processes
   b. The technology pull office will coordinate with and leverage the DOE Applied Energy Offices (Energy Efficiency and Renewable Energy. Fossil Energy, Nuclear Energy, Office of Electricity, and Office of Environmental Management) as well as small/large industry and venture capital community to identify technology and market gaps.
3. Based on push and pull knowledge, workshops are held to bring multiple communities together to identify technical challenges and opportunities that connect science to technology and markets
4. Based on the community input, the program director will propose a new program within ARPA-E at the intersection of technology push and pull that addresses both science and markets. As part of this proposal, the program director will answer a set of questions on ARPA-E program criteria (see below). There will be an internal debate that will involve all the other ARPA-E program directors, me, and other relevant program managers within the DOE.
5. After feedback from other program directors within ARPA-E as well as other offices within DOE, a new program will be created.

Program Criteria: The 10 questions that each program director has to address to create an ARPA-E program are:

1. What is the global landscape of the field – science, technology, markets, players?
2. What are the major gaps and "white spaces"? Have you coordinated with the rest of DOE?
3. What's new and why is it a potential game-changer?
4. Is there room for left-field ideas? Can your goal be reframed to achieve a better outcome?
5. If successful, what potential impact can it make in terms of quantitative metrics?
   a. *Energy independence & security*
   b. *Reduction of GHG emissions*
   c. *Technological lead for US*
6. Who will adopt this technology? Who are the customers?
7. Will it scale in cost and volume? What instruments (financial, policy, etc.) do you need downstream for scaling? Are there non-technical barriers (policy, markets)?
8. Who are the potential teams and players?
9. What is your potential risk profile and time horizon – low, medium, high, short/long-term?
10. How much will it cost and why?

Where the first FOA was open to all technologies, the programs in the second FOA round (BEEST, IMPACCT, and Electrofuels) and the third FOA round (GRIDS, BEETIT, and ADEPT) were successfully created via such a process. Each program will go through three screening or review process steps to identify projects that can be funded – a five-page concept paper stage that will involve an external review panel, a full application stage that will also involve a second and different review panel, and finally an internal vetting process involving the program director and the ARPA-E Director. The concept papers and full applications are reviewed by a panel of reviewers that consist of distinguished members of the technical community as well as technical leaders within DOE.

Coordination within DOE and other Stakeholders

The coordination and leveraging within DOE is an important issue for ARPA-E. To enable this, we have created the Panel of Senior Technical Advisors, or PASTA. The members of PASTA are a group of technical leaders within DOE spanning the Office of Science, Fossil Energy, Nuclear Energy, Energy

Efficiency and Renewable Energy, and many others. PASTA will meet at least twice a year to discuss the following items:

1. What programs ARPA-E is running;
2. Some results from these programs that may have impact on other parts of DOE;
3. Interesting proposals and ideas that we could not fund that may be relevant for other parts of DOE;
4. Plans for recruiting, technical workshops, and future programs;
5. Scientific and technical gaps and challenges that we have encountered;
6. Any breakthroughs from other offices of DOE that are relevant to ARPA-E; and
7. Coordination between Energy Frontier Research Centers (EFRC), Energy Innovation Hubs (Hubs), and ARPA-E.

It is important to point out the differences and coordination between EFRCs, Hubs, and ARPA-E:

- EFRCs focus on small teams exploring basic science issues.
- Hubs will ideally be located under one roof and will bring together a diverse team of researchers spanning basic and applied. Their work will have a common goal, but will require addressing multiple challenges in a coordinated and focused way. The Hubs are modeled after the Office of Science Bioenergy Research Centers.
- ARPA-E is modeled after DARPA, i.e. it will invest in high-risk/high-payoff time-bound projects focused on combining various science and engineering discoveries and inventions into energy technologies with potentially commercial impact.

The feedback loop, coordination and leveraging between EFRCs, Hubs and ARPA-E is critical. The scientific discoveries and inventions made in EFRCs and Hubs could lead to ARPA-E technologies with significant commercial impact. A historical example of this is the invention of the transistor leading to integrated circuits – this translation required both science and engineering of devices and manufacturing. Furthermore, it is important to note that during this translation, one may encounter major technical barriers, which will require going back to science to solve them. Hence, EFRCs and Hubs could leverage off of ARPA-E as well. As mentioned above, the Hubs are designed to ideally be located under one roof. However, if the Hub encounters a technical challenge that the Hub team cannot address, ARPA-E could engage teams from the rest of the nation to help address the challenge and enable the Hub to make progress.

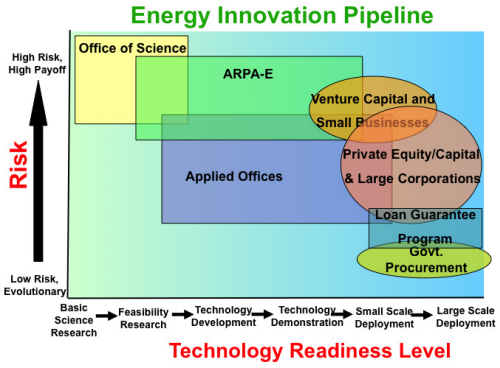

Figure 4 Energy innovation pipeline

In addition to technical coordination, it is important for ARPA-E to coordinate with other stakeholders. Figure 4 (above) shows a chart of the energy innovation pipeline that highlights the high-risk focus of ARPA-E and its interaction with DOE's Office of Science on the one hand and DOE's Applied Offices and the investment community on the other.

Final Comments

I recognize that these early days are a very critical period for ARPA-E. We are currently putting together our DNA and we must get this right by innovating in our internal processes. We have a new organizational structure that is not only nimble and agile, but one that breaks down potential silos

between various disciplines and encourages internal debate and discussion within the program in addition to coordination with the rest of DOE. I am also delighted to report that we have been able to recruit some of the best and the brightest from the technical community as program directors for a maximum of four years. We have also created the ARPA-E Fellows Program to recruit some of best young minds to join ARPA-E for a maximum of two years and help us craft new programs by identifying technological opportunities in the global energy landscape.

From my past experience in the R&D community, and through what I have now seen in ARPA-E, I can assure you that the innovation process is in full swing in the US. Energy is now receiving the attention of the best minds in our country and is attracting new talent. I am confident in saying that we are not limited by a lack of ideas. We still have the best R&D infrastructure in the world, and a thriving innovation ecosystem in business and entrepreneurship. I am very optimistic about our nation's future. I pledge to use all my knowledge, expertise, and experience to continue growing ARPA-E into a robust engine of American innovation in energy and environment.