Statement of

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Chairman Gordon, Ranking Member Hall, and members of this committee, thank you for the opportunity to testify today on 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 DOE with a mandate to identify and support the innovative and pioneering ideas and people that will be game-changing for our domestic and global energy landscape. It has been incredibly exciting for me and my team. 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 want to thank President Obama and Secretary Chu for their trust in me to serve as the first Director of ARPA-E, the Senate for confirming me in this position, and to Congress for authorizing and appropriating ARPA-E. I especially want to recognize Chairman Gordon and the members of this committee for all of their hard work in authorizing ARPA-E in the America COMPETES Act.

Many people within the DOE have my deepest gratitude for their work to help launch ARPA-E before I joined as its Director on October 26, 2009. These include Secretary Chu himself, Undersecretaries Kristina Johnson and Steve Koonin, CFO Steve Isakowitz, DOE's *American Recovery and Reinvestment Act* Recovery Act Implementation team led by Matt Rogers, Shane Kosinski, as well as many staff members from the Offices of the General Counsel, and Procurement, along with the technical staff from the Office of Science and the Applied Energy Offices. I was very blessed to have their support before I joined, and I continue to rely on their expertise and effort.

1. Introduction

As this committee well knows, our dependence on fossil fuels threatens our energy and environmental security and creates significant challenges in addressing climate change. 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. The nation that successfully grows its economy with more efficient energy use, a clean domestic energy supply, and a smart energy infrastructure will lead the global economy of the 21st century. In many cases, we are lagging behind. We as a nation need to change course with fierce urgency.

ARPA-E was created to address this important issue, and it was created with DARPA as a model. It is important to understand the origins of DARPA, and also point out some of the key differences between the defense and energy sectors of our economy. DARPA, originally called ARPA, was created in 1958 in response to the launch of Sputnik by the Soviet Union. It was felt at the time that the U.S. had lost its technological lead, and that the nation needed an organization that would invest in

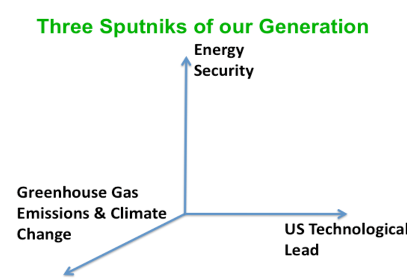

Fig. 1 The U.S. is now facing three "Sputniks" of our generation

high-risk/high-payoff R&D and connect technological innovation to business, which would then support the defense infrastructure.

The U.S. now faces three Sputnik-like challenges in the energy and climate area (see Figure 1): (a) energy security; (b) U.S. technological lead; and (c) greenhouse gas emissions and climate change. To illustrate where we are, I have included two snapshots of production key to future energy use. Figure 2 shows the trends in U.S. market share and shipments of photovoltaic solar cells – in a span of 15 years, the U.S. market share has decreased from 45 percent to less than 10 percent. Figure 3 shows the manufacturing volumes of Lithium-ion batteries in 2009. These batteries are being used in both mobile electronics (laptop computers, cell phones, etc.) as well as for plug-in hybrid and electric vehicles. It is noteworthy that the materials and chemistry that are used in these batteries were largely discovered here, yet the United States has about 1 percent of the global manufacturing volume.

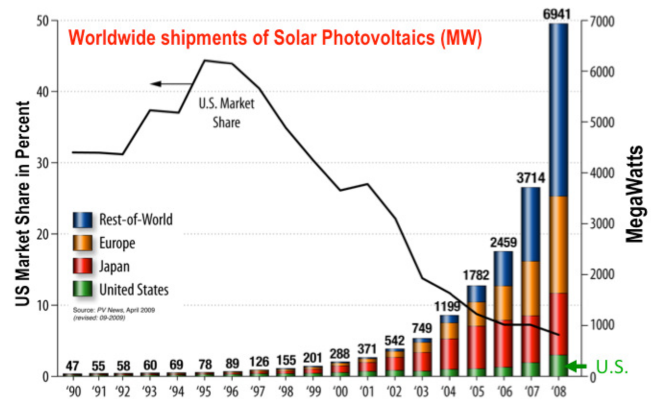

Fig. 2 Global comparison of solar cell shipments. Source: PV News, April 2009.

2. Scale and Pace of Innovation Needed in the Energy Sector

During the 20th century, certain key innovations changed the course of human history, including the Haber-Bosch process of creating artificial fertilizers by fixing atmospheric nitrogen to form ammonia. It touched humanity like none other because it led to massive increase in food production and an almost four-fold increase in global population in 100 years. Other game-changers included creating semi-dwarf, high-yield strains of wheat that introduced the green revolution; antibiotics; polio vaccination; the transistor and integrated circuits; electrification; the airplane; nuclear energy; optical and wireless communication; the internet; and more. Now imagine all of these innovations happening in a span of just 10-20 years: That is the scale and pace of game-changing innovations that we need to address the energy and climate change challenge we face. In short, the next 20 years need to be the most innovative period in our Nation's history.

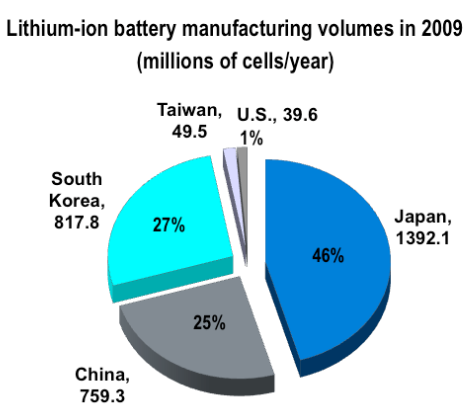

Fig. 3 Global distribution of manufacturing volume of Lithium-ion batteries in 2009.

Our history is replete with examples of pioneers and entrepreneurs who took risks. These innovators often failed initially, but quickly learned from those failures, competed against each other, and innovated in both technology and business to create the largest industrial base the world has ever seen.

ARPA-E's goal is to tap into this truly American ethos, and to identify and support the pioneers of the future. With the best R&D infrastructure in the world, a thriving innovation ecosystem in business and entrepreneurship, and a generation of bright young minds that is willing to engage with fearless intensity, we have all the ingredients necessary for future success. The goal of ARPA-E is to harness them to address our technological gaps and leapfrog over current approaches.

3. Creation of ARPA-E

Recognizing the need to reevaluate the way the United States spurs innovation, the National Academies released a 2005 report, "Rising Above the Gathering Storm", that included the recommendation to establish an Advanced Research Projects Agency—Energy (ARPA-E) within the Department of Energy (DOE). In August of 2007, Congress passed the America COMPETES Act which, among many of the recommendations in the National Academies report it codified, established ARPA-E with the following objectives:

1. To bring a freshness, excitement, and sense of mission to energy research 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 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 an ARPA-like organization that is flat, nimble, and sparse, capable of sustaining for long periods of time those projects 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.

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 American Recovery and Reinvestment Act of 2009 provided $400 million in funding for ARPA-E

With the first tranche of those funds having been awarded, I would like to provide a report on where we are now and our plans for the future.

4. First Funding Opportunity Announcement

4.1 Process: The first ARPA-E Funding Opportunity Announcement (FOA) was made in May 2009, and the FOA requested concept papers of transformational ideas spanning all aspects of energy science and technology. ARPA-E received approximately 3700 concept papers, significantly higher than expected. After these concept papers were reviewed, roughly 340 were invited to submit full proposals. These proposals were then reviewed by two sets of panels of external reviewers. Based on these reviews and a rigorous selection process, on October 26, 2009 the DOE selected awardees for $151 million of Recovery Act funds for 37 energy research projects under ARPA-E. The average funding level was $4M for a maximum of 3 years. The minimum and maximum funding levels were about $500K to $9M, respectively. Approximately 45% of the funding was received by small businesses, 35% by educational institutions, and the remaining 20% by large industry. National Laboratories team members participated in 19% of the funded projects.

Selections for ARPA-E's first FOA were announced Oct 26, 2009. By January 15, 2010, 35 out of 37 selections were awarded. This speed has now set records within the DOE, showing both the potential for ARPA-E to move quickly as consistent with its mission, and its ability to move Recovery dollars out the door in order to quickly create jobs.

<u>4.2 Funded Projects</u>: These 37 projects constituted the best ideas that, if successful, could be potential game-changers in the energy sector. These topics were chosen based on the following criteria:

- High impact on ARPA-E mission areas
- Innovative technical approaches
- Best-in-class people and teams
- Opportunities for U.S. to maintain/gain technology leadership
- "White Space" opportunities relative to existing DOE portfolio
- Topic areas underserved by private sector investment (e.g., both technical and market risk)
- Strong additionality/leveraged impact relative to private sector investment and other public funding programs

Let me provide a couple of examples from among the projects funded by the first FOA.

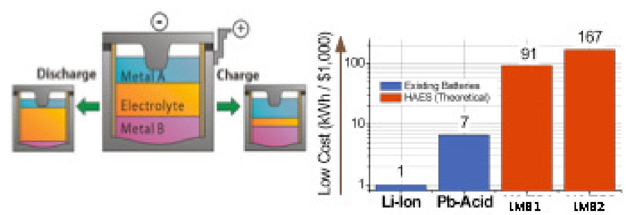

Fig. 4 Liquid metal battery could potentially be used for grid-level electrical energy storage (MW of power, MW-hr of energy) and at a cost of $50-100/kW-hr.

Figure 4 shows a large-scale liquid metal battery under development at the Massachusetts Institute of Technology. It is based on the innovative use of electroplating on two different metals from a mixture of two liquid metals. Based on low-cost, domestically available liquid metals, such a battery could lead to the mass adoption of grid-scale electrical energy storage as part of the nation's energy grid. The estimated cost of such a battery would be roughly $50-100/kW-hr, which would make it economical world wide. Grid-level electricity storage is one of the most challenging issues to make a "smart grid", and yet there are currently very few viable technologies that meet all the requirements for such an application.

Figure 5 shows the design of a new wind turbine developed by FloDesign Corp, a startup company based

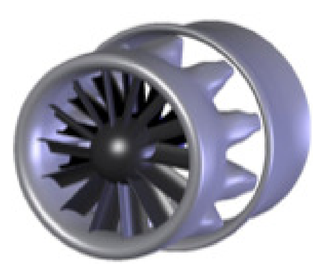

Fig. 5 New windmill design based on the engineering of jet engines

in Massachusetts. Today's windmills look like propellers with large blades mounted on a rotating horizontal axle, and they have an inherent limit (the Betz limit), capturing a maximum of about 60% of the wind energy. Today's windmills operate at about 50-55% efficiency, which is seen as almost the practical efficiency limit. FloDesign has used concepts from jet engine fluid dynamics and innovated in windmill design, which has now been able to beat the Betz limit. This breakthrough enables FloDesign to reduce the cost and size of windmills by roughly 40% while maintaining the same power level. Furthermore, the major loads are no longer on the rotating shaft and bearing, but rather on the stationary envelop, which reduces reliability problems and increase lifetime.

<u>4.3 Building a Constituency</u>: The nature of projects selected in FOA-1 has energized and engaged the technical and investment community. In addition to unveiling a pent-up fountain of ideas as evidenced by the overwhelming response to the solicitation, private capital has begun to come off the sidelines, which was one of the main goals of the Recovery Act. After ARPA-E announced its selections, the teams collectively received about $30M of private investments in less than 2 months, suggesting that if ARPA-E can reduce the technology risk, the private sector is willing to adopt the technology and potentially scale it in the market.

In fact, one ARPA-E awardee went as far as to say, "*Winning the ARPA-E award served as the catalyst for an over-subscribed financing round and recruitment of business executives.*"

<u>4.4 Speed of Transactions</u>: Selections for ARPA-E's first FOA were announced October 26, 2009. By January 15, 2010, 35 out of 37 selections were awarded. This speed has now set records within DOE, which is especially important considering that we are being funded through ARRA funds, all of which need to be obligated by September 30, 2010.

<u>4.5 Supporting Projects Not Funded:</u> One of my main goals in the near future is to nurture this interest in ARPA-E technologies. As noted above, of the 3,700 initial applications received, DOE only selected 37 for funding. Clearly, the first ARPA-E solicitation was oversubscribed and many excellent proposals could not be funded. We have encouraged and continue to encourage many of the teams who did not get funded to return to ARPA-E with their ideas for future workshops and to help us create new programs. We are also launching the ARPA-E Energy Innovation Summit March 1-3, 2009, in Washington, DC, where we not only want to highlight the technologies that we support, but also invite teams that did not get funded, so that we can connect them to other offices within DOE as well as other funding agencies and organizations. In short, I realize that we cannot financially support everyone, but we also realize that we need to build a large community beyond ARPA-E for our nation to change course with fierce urgency.

5. Next Funding Opportunity Announcements

On the heels of the first funding opportunity's success, Secretary Chu announced on December 7, 2009 the availability of a second round of funding opportunities for transformational energy research projects through ARPA-E. Funding Opportunity

Announcement 2 (FOA-2) will provide an additional $100 million in Recovery Act funding. In contrast to FOA-1, which was open to all topics related to energy, FOA-2 is focused on a set of three topics chosen from several workshops that ARPA-E hosted over a three-month period, where it received input from the technical community. Areas of focus included under FOA-2 are:

1. Electrofuels. ARPA-E seeks new ways to make liquid transportation fuels – without using petroleum or biomass – by using microorganisms to harness chemical or electrical energy to convert carbon dioxide into liquid fuels.
2. Innovative Materials & Processes for Advanced Carbon Capture Technologies (IMPACCT). To address the enormous challenge of reducing the cost of carbon capture, ARPA-E is looking for low-cost catalysts to enable systems with superior thermodynamics that are not currently practical due to slow kinetics, robust materials that resist degradation from caustic contaminants in flue gas, and advanced capture processes
3. Batteries for Electrical Energy Storage in Transportation (BEEST). ARPA-E seeks to develop a new generation of ultra-high energy density, low-cost battery technologies for long electric range plug in hybrid electric vehicles and electric vehicles (EVs).

We are now in the process of organizing another set of workshops, the results of which we will use to plan the next set of FOAs (FOA-3) sometime in early Spring. FOA-3 will be the last funding under ARRA funds, and we will obligate these awards before September 2010.

6. The DNA of ARPA-E

I firmly believe that if we are to stimulate innovations in technology in the techno-business community, ARPA-E itself must be innovative. My vision includes:

- *Organization*: Flat, nimble, agile, collaborative, internal debates and discussions;
- *Excellence in People & Ideas*: An all-star team at ARPA-E focusing on highly selective and potentially game-changing ideas;
- *Integrity*: New program creation and proposal review process;
- *Openness*: Open to best ideas regardless of origin, transparency, public understanding of value of technology for society, respond to community input;
- *Speed*: Streamline transactions and accelerate science to market;
- *Metrics of Success*: Quantitative value creation.

While we have adopted some best practices from DARPA based on statutory requirements as well as non-statutory ones, it is worth noting that the defense and energy sectors are by nature very different. The defense sector is almost a closed economy, and DARPA will always have a known customer, the

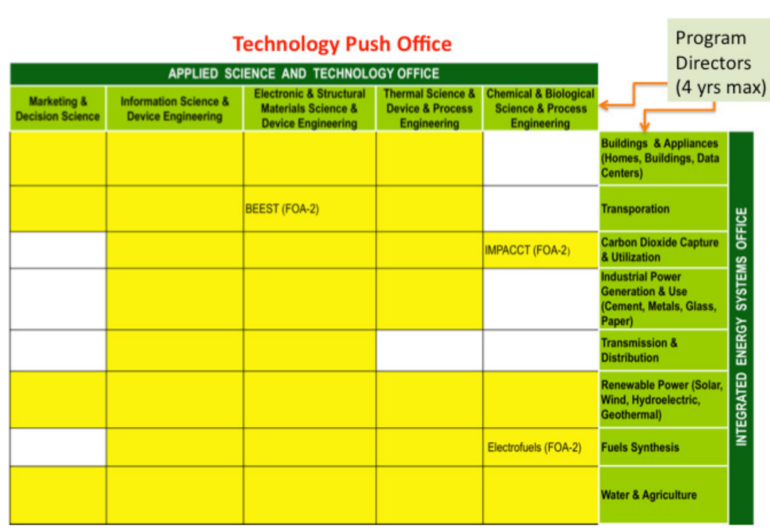

Fig. 6 Organizational structure of ARPA-E.

DoD. On the other hand, the DOE budget is a fraction of whole energy sector, and ARPA-E is a fraction of that. Hence, ARPA-E needs to identify the customers (both private and government) and must act as a catalyst for private investment for scaling the technologies downstream.

<u>6.1 ARPA-E Program Organization</u>: Figure 6 shows the program organization of the ARPA-E. The goal here is to break down silos. It is a matrix organization with two offices – Applied Science and Technology Office (or the Technology Push Office) and the Integrated Energy Systems Office (or Technology Pull Office). The Program Directors will be responsible for either a Technology Push Program or a Technology Pull Program, i.e., they will sit on the periphery of this matrix. The matrix structure is created in order to foster debate and discussion when a FOA for a program is created. For example, if a Program Director from the Technology Push Office wants to create a program FOA, he/she needs to convince the Program Directors in the Technology Pull Office that the device or process will be useful for a system. On the other hand, if a Program Director in the Technology Pull Office wants to create a program, he/she needs to integrate across disciplines in the Technology Push Office. As an example, Figure 6 shows the three FOA-2s at the intersection of Technology Pull and Push Offices. I believe the tension and constructive debate that such an organization creates is healthy, and will lead to much more collaboration and interactions between various disciplines.

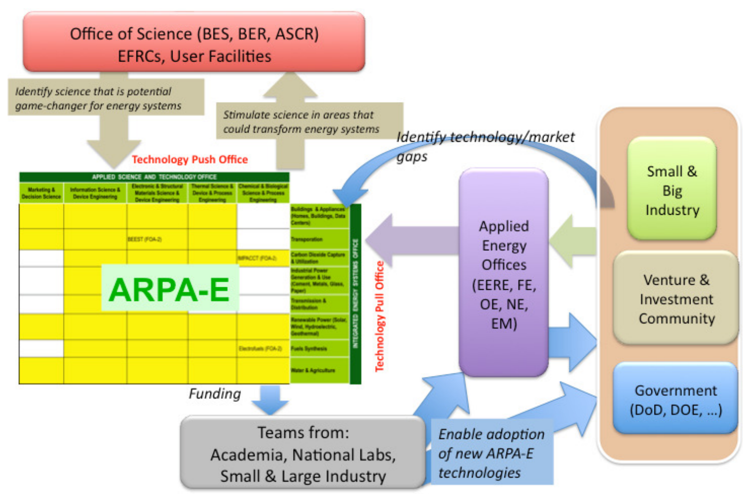

Fig. 7 Coordination of ARPA-E within DOE.

Figure 7 shows the coordination of this organization structure within the DOE. The Technology Push Office interacts with the Office of Science, such that if a discovery is made that could have significant impact on energy systems, ARPA-E would be ready to accelerate technology development based on the scientific discovery. On the other hand if science is missing in a certain energy-related area, ARPA-E could inform Office of Science to pursue the underlying science. The Technology Pull Office will interact with the Applied Energy Offices to identify technology and market gaps. The Technology Pull Office will also interact directly with small and large industry, the venture and investment communities, as well as government agencies. Based on all these input, programs will be created and teams will be funded. These teams will then create technologies, which could be adopted via leveraging the deployment programs within the

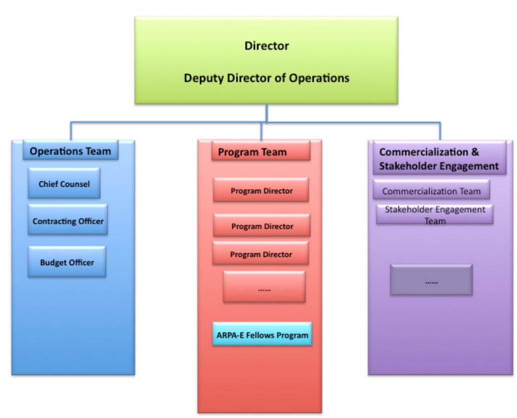

Fig. 8 Organizational structure of ARPA-E

Applied Offices, or directly by the industry, investment community, or government.

6.2 ARPA-E Organization Structure: Figure 8 shows the organizational structure of ARPA-E. It has three teams that work collaboratively – the operations team, the program team, and the commercialization/stakeholder engagement team. All personnel report to the Director and Deputy Director of Operations.

Currently, ARPA-E is relatively small in size, and this organizational structure will suffice. As the size grows, the structure will evolve as well, and I look forward to returning to this committee with updates and requests for suggestions as this evolution continues.

6.3 Program Directors: The selection of program directors is critical to the success of ARPA-E. The people I am currently recruiting are those that have one foot in science (active researchers) and the other foot in technology development and business. These include people from academia or national labs who are very active in research, and may have started businesses or worked closely with industry, or people from the industry who are still involved in science research.

6.4 ARPA-E Fellows Program – Leveraging Our Strength: There is a grassroots movement in the U.S. where the youth have broken barriers between science, engineering, business, law, and public policy and have come together to work in energy. To tap into this body, we have created the ARPA-E Fellows program. This program will bring the best and brightest to ARPA-E, and have them serve the nation for a maximum of 2 years. During this time, they will be an internal think tank to step back from our current programs and identify new ways of creating technologies that can have game-changing impact on our and the world's energy economy.

7. Role of ARPA-E in the Energy Innovation Pipeline:

ARPA-E will invest in high-risk/high-payoff technologies which could be potential game-changers. However, ARPA-E investments will be upstream in the whole development process. For these technologies to scale in volume/size and also in cost, it is important to understand the downstream process as well, and identify mechanisms to create a market pull or reduce the risk for further large-scale investments. Figure 9 shows a conceptual plot of the DOE portfolio and private investment instruments. For

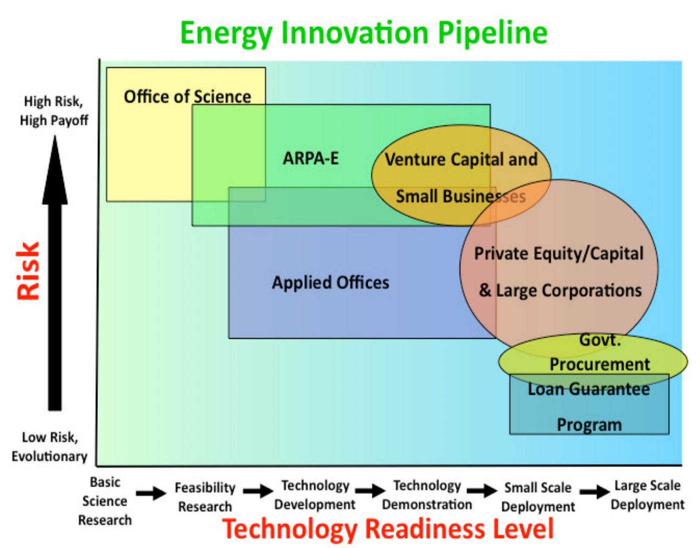

Fig. 9 Energy innovation pipeline in terms of risk versus technology readiness levels with DOE and private investments

ARPA-E to be successful, it is important ARPA-E understands, utilizes, and facilitates technology transition in this landscape.

It is also important to note that Figure 9 does not apply to all technologies. For centralized technologies, such as carbon capture or power plants, one needs to have demonstration projects that show both technical and economic performance before the risk is sufficiently reduced for large investments. On the other hand, decentralized energy technologies (e.g., batteries for vehicles) may follow a different route and therefore need not be limited by large demonstration projects.

8. Metrics of Success

Since the authorization of ARPA-E, there have been high expectations for its success. It is important for us to manage these expectations. In the energy sector, home runs are rarely hit in a couple of years. Therefore, it is important for us to define the metrics of success as a function of time. Figure 10 shows three stages in time. It is relatively easy to show some element of success now, which is listed in the figure. It is unlikely that the true impact of a technology can be felt in less than 10 years. But it is relatively easy to define success 10+ years from now – if an energy technology is truly game-changing, then it will have a major impact on the market, on people, on jobs, and various other metrics listed in Figure 10. Perhaps the most difficult metrics of success are in the next 3-5 years. The metrics listed in Figure 10 in this time period are what we can demonstrate in the near future. We will keep track of these metrics in a quantitative fashion and I will be happy to share them with Congress from time to time.

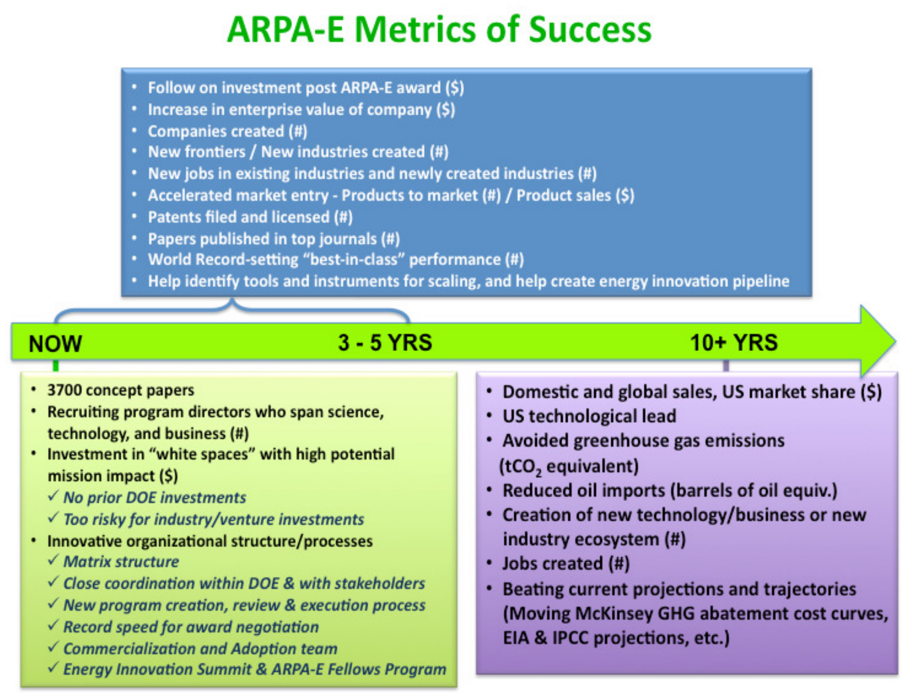

Fig. 10 ARPA-E metrics of success and timeline

9. Beyond the Recovery Act

As I noted earlier, we have a plan in place to spend the Recovery Act funds allocated to ARPA-E. Once those funds are exhausted, we must continue to invest in high-risk, high-reward technologies in order to achieve major breakthroughs in energy like those I highlighted at the beginning of my testimony. I look forward to working with the members of this committee and many others going forward in order in order to allow Congress' vision for ARPA-E to reach its full potential.

Again, I thank you for the opportunity to testify before this Committee, and I am happy to answer any questions you may have at this time.