Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future

Testimony Regarding

Should Congress Establish "ARPA-E," The Advanced Research Projects Agency – Energy?

Statement of

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And

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Committee on Science, Engineering, and Public Policy
Division on Policy and Global Affairs
National Academy of Sciences, National Academy of Engineering, Institute of Medicine

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Chairman Boehlert, Ranking Member Gordon, Members of the Committee.

I am Steven Chu, director of Lawrence Berkeley National Laboratory. Prior to my current job, I was at Stanford University for 17 years and at AT&T Bell Laboratories for 9 years. I was the co-winner of the 1997 Nobel Prize in Physics.

I was privileged to serve under Norman Augustine as a member of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine's Committee on Prospering in the Global Economy of the 21st Century that produced the report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. I come before you today as a representative of the Augustine Committee, and not the Department of Energy.

Thank you for providing me with the opportunity to contribute to today's discussion on the utility of the committee's proposal for the Advanced Research Projects Agency – Energy (known as ARPA-E).

INTRODUCTION

We live in a truly magical time. With the flick of a finger, the power of 10 horses flows from a small wire in the wall of our homes to clean our carpets. We go to the local market under the pull of hundreds of horses and fly across our continent with tens of thousands of them. Our homes are warm in the winter, cool in the summer and lit at night. We live well beyond the dreams of Roman emperors.

What has made all of this possible is our ability to exploit abundant sources of energy. The worldwide consumption of energy has nearly doubled between 1970 and 2001. By 2025, it is expected to triple. The extraction of oil, our most precious energy source, is predicted to peak sometime in 10 to 40 years, and most of it will be gone by the end of this century. What took hundreds of millions of years for nature to make will have been consumed in 200 years. We have abundant forms of fossil fuel such as coal, shale oil, and tar sands that will last for hundreds of years. However, in my opinion, if the world substantially increases the generation of greenhouse gases by relying heavily on fossil fuels, we run the risk of causing disruptive climate change.

The nation needs to develop clean, safe, secure, and sustainable energy for three reasons:

1) Our energy security is directly linked to national security.

2) Economic competitiveness is intimately tied to how much energy costs, and how efficiently it is used.

3) There are serious environmental concerns associated with energy usage from local pollution to climate change.

Because of these concerns, I believe that the energy problem is ***the*** *single most important problem* that has to be solved by science and technology in the coming decades. At present, there appear to be no magic bullets to solve the energy problem. While efficiencies play a huge role in defining how much energy we consume, we must also have a diversified portfolio of investments to develop sustainable sources of energy.

ARPA-E

The committee that developed the report, *Rising Above the Gathering Storm*, included amongst its 20 recommended action steps, the establishment of the Advanced Research Projects Authority – Energy (ARPA-E).

The committee intends ARPA-E to provide a new field of opportunity to the Department of Energy as it works to develop new technologies to supply this nation and the world, with safe, clean, affordable, secure, and sustainable energy. We simply must find energy supplies that will not degrade our environment. If we do not do this, there will be no future prosperity.

We must take concerted action and make the investments necessary to enlist our most talented researchers and innovators. Our committee, therefore, conceived ARPA-E as an organization reporting to the DOE Under Secretary for Science that can achieve four objectives:

1.Bring a freshness, excitement, and sense of mission to energy research that will attract many of our best and brightest minds – those of experienced scientists and engineers, and, especially, those of students and young researchers, including those in the entrepreneurial world.

2.Focus on creative "out-of-the-box" 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.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.

4.Create a new tool to bridge the gap between basic energy research, and development/industrial innovation.

The agency would itself perform no research, but would fund work conducted by universities, start-ups, established firms and national laboratories. Although the agency would be focused on energy issues, it is expected that its work (like that of DARPA or NIH) will have important spin-off benefits, including aiding in the education of the next generation of researchers.

Another goal of ARPA-E is to bring teams of the best researchers across departments and schools to get the best results for the nation. ARPA-E would provide an incentive to encourage the best and brightest researchers to pursue more applied work than they would normally pursue. It could also serve as a model for how to improve the transfer of science and technology research in other areas that are essential to our future prosperity.

The committee considered several models before deciding to focus on energy and to use ARPA as a template. Among these were In-Q-Tel (which engages the entrepreneurial community with technologies of potential interest to the intelligence community), HSARPA (the Department of Homeland Security Version of ARPA), SEMATECH (a jointly funded research venture of the federal government and the semiconductor industry), Advanced Technology Program (ATP), Small Business Innovation Research program (SBIR), Civilian Technology Corporation (recommended in a previous 1992 National Academies report chaired by Harold Brown), and Discovery Innovation Institutes (recommended by a 2005 National Academies report chaired by James Duderstadt).

In-Q-Tel is a fine model for its mission. However, the objective set out by the *Gathering Storm* report is to perform research and to sponsor the early development of transformational new approaches to energy. In-Q-Tel operates in a different context. Its goal is not basic research, but the application of those ideas already in business and to act as a bridge from one industry to another. On the other hand, the goal of ARPA-E is to conduct applied research and to act as a bridge from basic research to development of new technologies.

Also, In-Q-Tel has one customer, the Intelligence Community, with a well-specified set of mission activities that they want to accomplish differently or better. Developing new energy technologies is an earlier-stage, much less focused activity. If ARPA-E is successful, then technology transition will be from the research laboratory to small and large companies, not into the government. Arguments compel the conclusion that DARPA is better model for ARPA-E where the challenge is to transform U.S. energy dependence.

Three congressional bills, HR 4435, S 2196, and S 2197 call for the establishment of ARPA-E. Although the National Academies do not endorse legislation, we can say that each of these bills is harmonious with the general principles outlined for ARPA-E in the Gathering Storm report. We believe the specifics of implementation are best determined by policymakers in Congress and at the Department of Energy.

FUNDING OF ARPA-E

Funding for ARPA-E would start at $300 million the first year and increase to $1 billion per year over 5-6 years, at which point the program's effectiveness would be evaluated and any appropriate actions taken.

In funding ARPA-E, it is critical that its funding not jeopardize the basic research supported by the Department of Energy's Office of Science. The

committee's recommendations are prioritized and its top recommendation in the area of research is to increase the funding for basic research by 10% per year over the next seven years. The Augustine Committee applauds the Administration's American Competitiveness Initiative, particularly the courageous efforts of Secretary of Energy Samuel Bodman, to make basic research activities a high priority in the Department of Energy budget .The Augustine Report strongly recommends the support of ARPA-E come from new funding.

I also note that the number one priority in our report is to fix K-12 science and mathematics education.

A critical factor in ARPA-E's success is that the funds be used as wisely as possible to fund the best ideas. These ideas should bubble-up from the bottom and should not be directed from the top. By placing ARPA-E under the Undersecretary of Science, the committee believes that this goal can be reached and earmarking of funds can be avoided.

WHAT RESEARCH MIGHT ARPA-E FUND?

Some examples of what ARPA-E might fund include:

1. **The development of a new class of solar cells.**

Photovoltaic solar cells using semiconductor technology can be very efficient at converting sunlight into electrical energy, but the fabrication cost remains too high. Organic and polymer solar cells can be made at low cost, but the efficiencies are low and existing materials degrade in sunlight. One promising avenue towards inexpensive, efficient and long lasting solar cells is to create novel materials based on multiple elements that can be manufactured with thin-film technologies. Another approach is to create nano-particle devices (distributed junction solar cells) that use different nanostructures for the conversion of sunlight into charge carriers and for the collection of those charges onto electrodes.

2. **Biomass substitutes for oil.**

The ethanol for transportation is currently produced from sugar cane, corn or other plants. However, the most cost effective bio-fuels will come from the conversion of cellulose into chemical fuel. When the fuel is burned, CO_2 is released into the atmosphere, but the overall cycle can, in principle, be carbon neutral. The creation of crops raised for energy will also take full advantage of our great agricultural capacity.

ARPA-E can fund the creation of new plants to be grown for energy by incorporating a number of genes are introduced into plants. Recently, a team of scientists at Lawrence Berkeley National laboratory inserted many genes into bacteria to produce an extremely effective anti-malarial drug. The Gates Foundation has given this team a $42 M grant to commercialize the technology so that the drug can be made available to the developing world. Similar technology can be used to

make plants self-fertilizing, drought and pest resistant. Note that about 25% of the energy input in growing corn comes from fertilizer, which is made from ammonia derived from natural gas.

Research on more efficient conversion of cellulose into liquid fuel would also yield great dividends. Current methods use the high temperature/ high acid processes that are very energy intensive. The breakdown of cellulose into ethanol is also accomplished with bacteria or fungi, but this process can be made much more efficient if the micro-organisms are modified with these methods.

COMMITTEE'S QUESTIONS ABOUT ARPA-E

In your request asking me to testify at this hearing, you asked me to respond to three questions about ARPA-E. I will now address each question.

1) Should ARPA-E be designed more to foster directed basic research or to get products into the marketplace? If the focus were basic research, what steps would ARPA-E or other entities have to take to affect the marketplace? If the focus were technology transfer, what specific barriers would ARPA-E be designed to overcome, how would it do so, and would that be the most effective way that government could transform the energy marketplace?

The purpose of ARPA-E is not to get products into the marketplace, but to conduct the research necessary to transform the energy marketplace by creating platform technologies. ARPA-E would identify and support the science and technology critical to our nation's energy infrastructure and act as the bridge between the basic research, predominantly supported by the Office of Science and the more applied areas.

The committee believes that there are great researchers and great ideas out there which are not currently being utilized to address the nation's energy challenge. Because the benefits of long-term energy research would accrue to all, it is not necessarily beneficial for one company to make the long-term investment needed for a transformational technology today.

Historically, this role was served by the great industrial labs such as Bell Labs which created devices such as the transistor. In the 1930s, there was a need to develop a low-power, reliable, solid-state replacement for the vacuum tube used in telephone signal amplification and switching. Materials scientists had to invent methods to make highly pure germanium and silicon and to add controlled impurities with unprecedented precision. Theoretical and experimental physicists had to develop a fundamental understanding of the conduction properties of this new material and the physics of the interfaces and surfaces of different semiconductors. By investing in a large-scale assault on this problem, the transistor was invented in 1948, less than a decade after the discovery that a semiconductor junction would allow electric current to flow in only one direction. Fundamental understanding was recognized to be essential, but the goal of producing a vacuum tube substitute was kept front-and-center. Despite this focused approach,

fundamental science did not suffer: a Nobel prize was awarded for the invention of the transistor. During this and the following efforts, the foundations of much of semiconductor-device physics of the 20th century were laid.

ARPA-E could fund research at universities start-ups, established firms and national laboratories for similar focused goals. ARPA-E may be especially useful in funding projects whose success will require coordinated efforts from several fields of science. It would also meet the nation's need for transformational, high-risk, high payoff R&D that would be a challenge for today's electric utilities, petroleum companies, and large energy equipment manufacturers to address and which are not very attractive to the entrepreneurial world.

2) *What kinds of entities should receive funding from ARPA-E? Should the National Laboratories be able to receive funding from ARPA-E? How should the work funded by ARPA-E differ from work funded under existing DOE basic and applied research programs? How could Congress structure ARPA-E to ensure that ARPA-E did not end up carrying out programs that are substantially similar to those already in DOE's portfolio?*

The research work supported by ARPA-E would fall between DOE's Office of Science and its energy technology programs such as the offices of Energy Efficiency & Renewable Energy, Nuclear Energy, Science, and Technology, Fossil Energy, Electricity Delivery and Energy Reliability. By its nature, ARPA-E would fund activities more applied than DOE basic research programs and too basic for its applied research programs. ARPA-E would also be looking for ways to harness basic science discoveries that are supported by other agencies.

Some key differences between ARPA-E and existing DOE organizations include:

- Small staff of smart, vigorous, creative minds with deep knowledge in relevant research areas hired from the best performing organizations in energy research and advanced energy industry.
- Creative, challenging programs that attract the brightest researchers in industry and the university to work on them.
- Programs designed with no constraint to fund existing organizations.
- Staff would also rotate on a regular basis as is the case at DARPA today to ensure that new ideas are constantly part of the mix. Staff's performance would be evaluated on their basis to identify and support transformative research.
- Programs with clear and challenging goals. For example, the DARPA speech recognition program started with a clearly defined goal such as recognizing a) continuous speech (words not disjointed), b) spanning a 1,000 word vocabulary, c) using conventional microphones, and d) performing recognition in real time.
- Programs defined to perform R&D of the multiple, complementary elements that enable new energy approaches to eventually become commercialized.
- Objective is breakthrough, new workable ideas – not incremental research.
- Flat management.
- Jumpstarts the adoption of a technology by inserting prototypes to demonstrate effectiveness. For example, it was DARPA not the military, that

developed the Predator, an unpiloted air vehicle that was used in theatre in the 1990s and greatly accelerated the adoption of such vehicles for surveillance and reconnaissance.

- Merit review of proposals.
- Operates with special authorities that enable the hiring of the needed talent, and that permit the agency to rapidly and nimbly make investments.

The criteria used to select proposals for research funding would be very important. Among them could be criteria that would describe how the proposed research is similar or different from existing research activities that DOE (or other organizations) is funding.

Another critical criteria would be that the research be transformational—not just incremental progress on existing ideas.

Anyone could compete for funding from ARPA-E including universities, industry, businesses, and national laboratories or ideally, a consortia of these organizations. Those managing the process would need to be very independent and not favor one group over another.

3) Is it credible to develop a solution to U.S. energy needs based on the Defense Advanced Research Projects Agency (DARPA), given that DARPA is developing ideas for a market in which the government itself is the primary customer and cost is not a primary concern?

The agency's basic administrative structure and goals would mirror those of DARPA, but there would be some important differences. DARPA exists mainly to provide a long-term "break-through" perspective for the armed forces. As previously stated, DOE already has excellent mechanisms for supporting long-term fundamental research in the Office of Science and shorter term research in its other branches. ARPA-E would identify and support the science and technology critical to our nation's energy infrastructure by focusing on problem-driven research. It also could offer several important national benefits:

- Promote research in the physical sciences, engineering, and mathematics.
- Create a stream of human capital to bring innovative approaches to areas of national strategic importance.
- Turn cutting-edge science and engineering into technology for energy and environmental applications.
- Accelerate innovation in both traditional and alternative energy sources and in energy-efficiency mechanisms.
- Foster consortia of companies, colleges and universities, and laboratories to work on critical research problems.

Although DOD is the primary direct customer for most successful DARPA-developed technologies, i.e. the military procures the ultimate systems, and devices, DOE would not in this sense be the direct customer for ARPA-E. In other words, it is really the defense industry that is the customer for DARPA who then in turn

uses its research to develop products it hopes is useful for DOD. DOD rarely builds products itself. Similarly, the energy industry could use the results of ARPA-E to similarly turn its research to develop technologies for itself, utilities, and the general public.

There are, however, vast potential world markets for successful new technologies that generate and distribute safe, clean, affordable, secure, and sustainable energy. Thus capital for proven technologies should not be a problem and an organization such as In-Q-Tel (which serves as a venture capital firm for the intelligence community) may or may not be necessary.

ARPA-E could be a catalyst to drive technologies into industry. It can take early high risk positions and access a talent base that generally is not available in the industry. Some ARPA-E projects would be conducted by industry, and would help to expand high-tech capabilities within companies, just as has been the case of DARPA projects in the defense industry.

Our committee did not believe it appropriate for us to specify the organization and mission of ARPA-E in great detail. We believe that must be worked out by the Secretary of Energy and the Under Secretary for Science in consultation with experts from the scientific and engineering communities. Defense visionaries who realized that the military had to reach out to new communities for the technologies that would be required to counter the rapidly changing threats of the post Sputnik era established the original ARPA in the DOD. It was enormously successful. We believe that ARPA will provide the right general framework on which to design ARPA-E. It is a proven model.

CLOSING COMMENTS

The potential payoff of ARPA-E through engaging new researchers, exciting a new generation to confront the looming energy crisis, and operating with an agility to involve scientists and engineers who otherwise might not contribute to meeting our energy and environmental challenges is great. ARPA-E can be goal-oriented, flexible, yet possible to start, stop, and sustain programs and projects according to their promise and performance.

Chairman Boehlert, Ranking Member Gordon, and Members of the Committee, thank you for the opportunity to National Academies report *Rising Above the Gathering Storm*. It is a privilege to work together to enable our nation to prosper in the 21st century.

I would be glad to respond to any questions.

STEVEN CHU is the director of E.O. Lawrence Berkeley National Laboratory, and a professor of physics and cellular and molecular biology at the University of California, Berkeley.

Previously, he held positions at Stanford University and AT&T Bell Laboratories. Dr. Chu's research in atomic physics, quantum electronics, polymer physics, and biophysics includes tests of fundamental theories in physics, the development of methods to laser-cool and trap atoms, atom interferometry, and the manipulation and study of polymers and biologic systems at the single-molecule level.

While at Stanford, he helped to start Bio-X, a multidisciplinary initiative that brings together the physical and biologic sciences with engineering and medicine.

Dr. Chu has received numerous awards and is a cowinner of the Nobel Prize in physics (1997). He is a member of the National Academy of Sciences, the American Philosophical Society, the American Academy of Arts and Sciences, and the Academica Sinica and is a foreign member of the Chinese Academy of Sciences and the Korean Academy of Science and Engineering.

Dr. Chu also serves on the boards of the William and Flora Hewlett Foundation, the University of Rochester, NVIDIA, and the (planned) Okinawa Institute of Science and Technology.

He has served on numerous advisory committees, including the Executive Committee of the National Academy of Sciences Board on Physics and Astronomy, the National Institutes of Health Advisory Committee to the Director, and the National Nuclear Security Administration Advisory Committee to the Director.

Dr. Chu received his AB and AB degrees in mathematics and physics from the University of Rochester, a PhD in physics from the University of California, Berkeley, and a number of honorary degrees.