Advanced Research Projects Agency - Energy (ARPA-E): Background, Status, and Selected Issues for Congress

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Summary

In August 2007, Congress authorized the establishment of the Advanced Research Projects Agency - Energy (ARPA-E) within the Department of Energy (DOE) as part of the America COMPETES Act (P.L. 110-69). Modeled on the Defense Advanced Research Projects Agency (DARPA), ARPA-E would support transformational energy technology research projects with the goal of enhancing the nation's economic and energy security.

Congress authorized $300 million for ARPA-E in FY2008 and "such sums as are necessary" for FY2009 and FY2010. Congress subsequently appropriated no funds for FY2008. The Bush Administration requested no funds for ARPA-E in FY2009, and took no actions to begin its operations. In the American Recovery and Reinvestment Act (ARRA; P.L. 111-5), Congress provided ARPA-E initial funding of $400 million which supplemented FY2009 funds of $15 million (P.L. 111-8). As a result, ARPA-E's received its initial funding of $415 million in FY2009. The ARRA funds are available for obligation until September 30, 2010. The Obama Administration requested $10 million for ARPA-E in FY2010. The House Committee on Appropriations declined to provide this funding. No Senate action has taken place.

Now that ARPA-E has received its initial funding, concerned members of Congress might wish to oversee its implementation to ensure that it achieves its goals. Several management design elements to monitor include the timely appointment of a director for ARPA-E, recruitment of highly qualified technical Program Managers familiar with the DARPA process, maintenance of autonomy from DOE's current activities, and sufficient funding and organizational flexibility. One concern is that the minimum number of scientific, engineering, and professional personnel required by the America COMPETES Act, 70, may be too high, at least in the initial stages, given ARPA-E's budget of $415 million.

On April 27, 2009, the Obama Administration announced the "launch" of ARPA-E and its initial solicitation for concept papers due June 2009. DOE expects to award $150 million of its $415 million FY2009 budget in response to this solicitation. No information was provided regarding ARPA-E's organization or staffing, or the amount of its $415 million FY2009 budget that will be used to fund those activities.

Besides overseeing the establishment of ARPA-E and its funding, an issue for Congress is how ARPA-E will differ from existing DOE Office of Science activities, including the new Energy Frontier Research Centers, the DOE energy technology offices, and the Energy Innovation Hubs proposed in the FY2010 budget. In addition, several bills introduced in Congress would either provide ARPA-E with additional authority or a source of funds, or require the Secretary of Energy to monitor its interaction with other proposed DOE research and development organizations.

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In August 2007, Congress authorized the establishment of the Advanced Research Projects Agency - Energy (ARPA-E) to support transformational energy technology research projects with the goal of enhancing the nation's economic and energy security.[1] Modeled on the Defense Advanced Research Projects Agency (DARPA) in the Department of Defense (DOD), ARPA-E would be a new organization within the Department of Energy (DOE) (see **Box 1 below**).

Overview of ARPA-E Design

As outlined in the America COMPETES Act (P.L. 110-69, §5012), the goal of ARPA-E is to enhance the economic and energy security of the United States through the development of technologies that reduce energy imports, reduce energy-related greenhouse gas emissions, and improve energy efficiency in all economic sectors. In addition, ARPA-E would aim to ensure that the United States is a technical leader in developing and deploying advanced energy technologies.

According to the act, ARPA-E would achieve this goal by identifying and promoting revolutionary advances in fundamental sciences and translating scientific discoveries and cutting-edge inventions into technological innovations. ARPA-E would focus its efforts on accelerating transformational technological advances in areas that industry, by itself, is not likely to undertake due to technical and financial uncertainty. As stated in §5012, the agency's programs would accelerate novel early-stage energy research with possible technology applications; the development of techniques, processes, and technologies and related testing and evaluation; research and development (R&D) of manufacturing processes for novel energy technologies; and coordination with nongovernmental entities to demonstrate technologies and research applications to facilitate technology transfer.

To achieve these goals, ARPA-E would make awards to academic institutions, companies, research foundations, and trade and industry research collaborations. In addition, awards may be made to consortia of these organizations, and these consortia could include federally funded research and development centers (FFRDCs). According to the act, the criteria for selecting projects would include novelty, scientific and technical merit, the demonstrated capability of the applicant to successfully carry out the proposed project, future commercial applications of the project, and the feasibility of partnering with one or more commercial entities, as well as additional criteria established by the director of ARPA-E.

[1] America COMPETES Act (P.L. 110-69), §5012. For more information, see CRS Report RL34328, *America COMPETES Act: Programs, Funding, and Selected Issues* and CRS Report RL34396, *The America COMPETES Act and the FY2009 Budget*, both by (name redacted).

Box 1. ARPA-E Management Design Keys

How does ARPA-E differ from the typical business-as-usual federal R&D management model? In congressional testimony, Steven Chu, now the Secretary of Energy, and other members of the committee that wrote the National Academies report, *Rising Above the Gathering Storm*, which proposed ARPA-E, recommended ARPA-E have four objectives that would distinguish it from current DOE activities:

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, potentially transformational research that industry cannot or will not support.

3. Utilize an ARPA-like organization that is flat, nimble, and sparse, yet capable of setting goals and making decisions that will allow it to sustain for long periods of time those projects whose promise is real, and to phase out programs that do not prove to be productive or as promising as anticipated.

4. Create a new tool to bridge the troubling gaps between basic energy research, development, and industrial innovation. It can serve as a model for how to improve science and technology transfer in other areas that are essential to our future prosperity.

Source: Testimony of Dr. Charles M. Vest, in U.S. Congress, Senate Committee on Energy and Natural Resources, *Protecting America's Competitive Edge—Energy*, hearings, 109th Congress, 2nd sess., February 14, 2006, S.Hrg. 109-358 (Washington: GPO, 2006), available at http://energy.senate.gov/public/index.cfm?FuseAction=Hearings.Testimony&Hearing_ID=1526&Witness_ID=4320. Testimony of Dr. Steven Chu, in U.S. Congress, House Committee on Science, *Should Congress Establish "ARPA-E", The Advanced Research Projects Agency - Energy?*, hearings, 109th Congress, 2nd sess., March 9, 2006, H.Hrg. 109-39 (Washington: GPO, 2006).

Management

The management of ARPA-E, as described in the act, is modeled on that of DARPA (see **Box 2 below**). DARPA has a well-known history of catalyzing innovative technologies, such as Saturn rocket engines used for moon flights, pilotless Predator planes used in Iraq and Afghanistan, computer-aided design, global positioning satellites, computer mouse, and Internet. DARPA seeks to sponsor revolutionary, high-payoff research that "bridges the gap between fundamental discoveries and their military use."[2] According to a former director, "DARPA will take a chance on an idea with no data. We'll put up the money to go get the data and see if the idea holds. That is the highest-risk type of research you can have."[3]

The act states that ARPA-E would be managed by a presidentially appointed director, who would report to the Secretary of Energy. The director would approve all new programs, develop funding criteria, establish technical milestones to assess program success, and terminate programs not achieving their goals. The director would have the authority to appoint not less than 70, and no more than 120, scientific, engineering, and professional personnel without regard to civil service laws and to determine their compensation. The director would be responsible for ensuring that ARPA-E activities are coordinated with, and do not duplicate, DOE and other federal programs and laboratory activities; the Program Managers would establish R&D goals and select projects based on merit.

[2] Testimony of Dr. Anthony Tether, Director, Defense Advanced Research Projects Agency, in U.S. Congress, House Committee on Science, *The Future of Computer Science Research in the United States*, hearing, 109th Cong., 1st sess., May 12, 2005, H.Hrg. 109-14 (Washington, DC: GPO, 2005) at http://science.house.gov/commdocs/hearings/full05/may12/tether.pdf.

[3] Anthony Tether as quoted in Stephen Barr, "The Idea Factory That Spawned the Internet Turns 50," *Washington Post*, April 7, 2008.

Both the director and the Program Managers would be permitted to seek advice on the overall direction of ARPA-E and specific program tasks from a new ARPA-E advisory committee or existing DOE federal advisory committees. Additional sources of advice provided for in the act include the President's Council of Advisors on Science and Technology (PCAST), professional organizations, and disciplinary societies.[4]

Box 2. DARPA Management Design Keys

How does DARPA differ from the typical business-as-usual federal R&D management model? According to DARPA, it has maintained the following management principles over its 50-year history:

Management: DARPA is a small, flexible, and flat organization with substantial autonomy and freedom from bureaucratic impediments. At DARPA, there is a complete acceptance of failure if the payoff of success was high enough. Management does focus on good stewardship of its taxpayer funds, but imposes little else in terms of rules. Management views their job as enabling DARPA's Program Managers.

Staff: Program managers are selected to be technically outstanding and entrepreneurial. The best DARPA Program Managers have always been freewheeling zealots in pursuit of their goals. The technical staff is drawn from world-class scientists and engineers with representation from industry, universities, government laboratories and Federally Funded Research and Development Centers. Technical staff are assigned for 3-5 years and rotated to assure fresh thinking and perspectives. Necessary supporting personnel (technical, contracting, administrative) are "hired" on a temporary basis to provide complete flexibility to get into and out of an area without the problems of sustaining the staff.

Projects: DARPA's activities are project-based. All efforts are typically 3-5 years long with strong focus on end-goals. Major technological challenges may be addressed over much longer times, but only as a series of focused steps. The end of each project is the end. It may be that another project is started in the same technical area, perhaps with the same Program Manager and, to the outside world, this may be seen as a simple extension. For DARPA, though, it is a conscious weighing of the current opportunity and a completely fresh decision. The fact of prior investment is irrelevant.

Source: DARPA, "DARPA Over the Years," webpage at http://www.darpa.mil/body/overtheyears.html.

Authorization of Funding

The act authorizes an Energy Transformation Acceleration Fund in the Department of the Treasury, with $300 million of funding authorized for FY2008 and "such sums as are necessary" for FY2009 and FY2010. ARPA-E's budget request and appropriations are to be separate and distinct from the rest of DOE's budget.

No more than 50% of ARPA-E funding may be used for coordination with nongovernmental entities for technology demonstration and research applications to facilitate technology transfer. At least 2.5% must be used for technology transfer and outreach activities. No funds may be used for construction of new buildings or facilities until August 2012.

Outcome Evaluation

After ARPA-E has operated for four years, the National Academy of Sciences (NAS) is to evaluate how well ARPA-E is achieving its goals and mission. The ARPA-E director would submit an annual report, describing projects supported in the previous year, as part of the annual budget request to Congress. The director would also submit strategic vision roadmaps to

[4] For a description of these organizations, see CRS Report RL34454, *Science and Technology Policymaking: A Primer*, by (name redacted).

Congress no later than October 1, 2008,[5] and October 1, 2011. The roadmaps are to describe the strategic vision ARPA-E would use to determine its future technology investments for the subsequent three fiscal years.

Funding

Congress authorized $300 million for ARPA-E in FY2008 and "such sums as are necessary" for FY2009 and FY2010. Congress subsequently appropriated no funds for FY2008. The Bush Administration requested no funds for ARPA-E in FY2009, and took no actions to begin its operations. In the American Recovery and Reinvestment Act (ARRA; P.L. 111-5), Congress provided ARPA-E funding of $400 million which supplemented FY2009 funds of $15 million (P.L. 111-8). As a result, ARPA-E's received its initial funding of $415 million in FY2009. The ARRA funds are available for obligation until September 30, 2010. The Obama Administration has proposed ARPA-E receive funding of $10 million in FY2010. The House Committee on Appropriations declined to provide this funding.[6] No Senate action has taken place.

Obama Administration Actions

President Obama announced the establishment of ARPA-E in a speech at the National Academy of Sciences. Shortly afterward, the Obama Administration released a funding opportunity announcement soliciting concept papers. The Administration has not announced ARPA-E's director or organization. These activities are discussed below.

President Obama

On April 27, 2009, President Obama in remarks at the National Academy of Sciences stated the following:

> And today, I'm also announcing that for the first time, we are funding an initiative—recommended by this organization—called the Advanced Research Projects Agency for Energy, or ARPA-E.
>
> This is based, not surprisingly, on DARPA, the Defense Advanced Research Projects Agency, which was created during the Eisenhower administration in response to Sputnik. It has been charged throughout its history with conducting high-risk, high-reward research. And the precursor to the Internet, known as ARPANET, stealth technology, the Global Positioning System all owe a debt to the work of DARPA.
>
> So ARPA-E seeks to do the same kind of high-risk, high-reward research. My administration will pursue, as well, comprehensive legislation to place a market-based cap on carbon

[5] No report was made in October 1, 2008. President Bush did not nominate an individual as ARPA-E director, and no actions were taken by the Bush Administration to establish ARPA-E.

[6] House Committee on Appropriations, Subcommittee on Energy and Water Development, "FY 2010 Energy and Water Development Appropriations," at http://appropriations.house.gov/pdf/EW_FY_2010_SubC_Summary_Table-06-25-2009.pdf. Note that the funding request for ARPA-E is listed as "Energy Transformation Acceleration Fund" in DOE's budget request and in this document.

> emissions. We will make renewable energy the profitable kind of energy. We will put in place the resources so that scientists can focus on this critical area. And I am confident that we will find a wellspring of creativity just waiting to be tapped by researchers in this room and entrepreneurs across our country. We can solve this problem.[7]

In a fact sheet that provided additional details regarding the speech, the Obama Administration stated the following:

> SPARKING THE CLEAN ENERGY REVOLUTION
>
> - As part of his plan to build a clean energy economy that will reduce our dependence on foreign oil and cut carbon pollution, the President will announce the launch of the $400 million Advanced Research Projects Agency-Energy (ARPA-E). In addition, the Department of Energy will announce grants to establish 46 Energy Frontier Research Centers.
>
> - ARPA-E is a new Department of Energy organization modeled after the Defense Advanced Research Projects Agency, the defense agency that gave us the Internet, stealth aircraft, and many other technological breakthroughs. The recommendation to create ARPA-E came from a report of the National Academy of Sciences entitled Rising Above The Gathering Storm, and funding for ARPA-E was included in the Recovery Act.
>
> - ARPA-E will award grants to recipients that enhance the economic and energy security of the United States through the development of breakthrough energy technologies; reduce the need for consumption of foreign oil; reduce energy-related emissions, including greenhouse gases; improve the energy efficiency of all economic sectors; and ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies.
>
> - ARPA-E will issue an initial solicitation that will focus on applicants with a well-formed R&D plan for a transformational concept or new technology that can make a significant contribution towards attainment of the President's Energy Plan. Under this announcement, ARPA-E will fund energy technology projects that (1) translate scientific discoveries and cutting-edge inventions into technological innovations and (2) accelerate transformational technological advances in areas that industry is not likely to undertake independently because of high technical or financial risk.[8]

Funding Opportunity Announcement

Later that day, the DOE released a Funding Opportunity Announcement (FOA) with ARPA-E's first solicitation.[9] The solicitation states the following:

> This is the first solicitation for the Advanced Research Projects Agency – Energy (ARPA-E). ARPA-E is a new organization within the Department of Energy (DOE), created specifically

[7] White House, "Remarks by the President at The National Academy Of Sciences Annual Meeting," speech, April 27, 2009, at http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-at-the-National-Academy-of-Sciences-Annual-Meeting/.

[8] White House, "Fact Sheet: A Historic Commitment To Research And Education," April 27, 2009, at http://www.whitehouse.gov/the_press_office/Fact-Sheet-A-Historic-Commitment-To-Research-And-Education/.

[9] This solicitation is available at http://www.energy.gov/media/ARPA-E_FOA.pdf.

> to foster research and development (R&D) of transformational energy-related technologies. Transformational technologies are by definition technologies that disrupt the status quo. They are not merely better than current technologies, they are significantly better. Often, a technology is considered transformational when it so outperforms current approaches that it causes an industry to shift its technology base to the new technology. The Nation needs transformational energy-related technologies to overcome the threats posed by climate change and energy security, arising from its reliance on traditional uses of fossil fuels and the dominant use of oil in transportation.
>
> ARPA-E will fund scientists and technologists to take an immature technology that promises to make a large impact on the ARPA-E Mission Areas (see Section I.B) and develop it beyond the "valley of death" that prevents many transformational new technologies from becoming a market reality. The "valley of death" generally occurs in two phases. The first phase occurs at the point of determining whether a laboratory stage technology can ever become a real-world technology or it has some inherent unsuitability for real-world applications. Once it has been determined through R&D that the apparent barriers can be overcome and how they may be overcome, then additional investment from many other sources causes a new field of technology options to open up. The second phase of the "valley of death" occurs at the point of developing the immature transformational technology to the point where key risks have been lowered enough that industry can invest in the final stages of development and incorporate the technology into products.
>
> Success for ARPA-E as an organization will be gauged by (a) whether its portfolio of investments includes the most promising transformational energy technology options and (b) the agency's ability to form and manage R&D efforts to mature these technologies rapidly. In the end, the nation will judge ARPA-E on whether these technologies come to market and are being used widely enough that they make a significant difference to reductions in domestic oil use and energy-related emissions of greenhouse gases.[10]

Proposers will initially submit a concept paper by June 2, 2009. ARPA-E will inform applicants by July 13, 2009, if they should submit a full application. The FOA indicates that ARPA-E anticipated most awards will be for projects in the $2 million-$5 million range, though some may be as low as $500,000 and as high as $20 million. In addition, ARPA-E anticipates making multiple awards, and awarding agreements totaling up to $150 million. The period of performance for awards is expected to be no more than 24 months, with a 36-month maximum. A minimum of 90% of work, as defined by total project costs, must be performed in the United States.

No information is provided in the FOA regarding ARPA-E's organization or staffing, or the amount of its $415 million FY2009 budget for those activities. Given DOE expects to award $150 million in response to this first solicitation, $265 million remains of this budget for ARPA-E administration and possible future awards.

What Research Might ARPA-E Support?

According to the America COMPETES Act, ARPA-E has the general goal

[10] Department of Energy, "Advanced Research Projects Agency – Energy (ARPA-E): Funding Opportunity Number: DE-FOA-0000065," CFDA Number: 81.135, April 27, 2009, at http://www.energy.gov/media/ARPA-E_FOA.pdf. Submissions may be made through the grants.gov website at http://www.grants.gov/search/search.do?mode=VIEW&flag2006=false&oppId=47045.

(A) to enhance the economic and energy security of the United States through the development of energy technologies that result in

(i) reductions of imports of energy from foreign sources;

(ii) reductions of energy-related emissions, including greenhouse gases; and

(iii) improvement in the energy efficiency of all economic sectors; and

(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies.

ARPA-E is to achieve these goals through energy technology projects by—

(A) identifying and promoting revolutionary advances in fundamental sciences;

(B) translating scientific discoveries and cutting-edge inventions into technological innovations; and

(C) accelerating transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty.

Secretary of Energy Steven Chu

In 2006, during congressional testimony provided to the House Committee on Science prior to becoming Secretary of Energy in the Obama Administration, Dr. Steven Chu suggested the following as research that ARPA-E might fund:

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 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 [million] 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.[11]

Since becoming Secretary of Energy, Secretary Chu reportedly contends that "solving the world's energy and environment problems would require Nobel-level breakthroughs in three areas: electric batteries, solar power and the development of new crops that can be turned into fuel."[12] Further, that a "'revolution' in science and technology would be required if the world is to reduce its dependence on fossil fuels and curb the emissions of carbon dioxide and other heat-trapping gases linked to global warming."[13] Additionally Secretary Chu reportedly believes that solar technology "will have to get five times better than it is today, and scientists will need to find new types of plants that require little energy to grow and that can be converted to clean and cheap alternatives to fossil fuels," and that alternatives must be found to burn coal cleanly as other countries are unlikely to discontinue its use.[14]

DOE Basic Energy Sciences Advisory Committee Report

In December 2008, a DOE Basic Energy Sciences Advisory Committee (BESAC) subcommittee released a report entitled *New Science for a Secure and Sustainable Energy Future*, based on reports from a series of workshop and a panel on Grand Challenges report held over several years.[15] The report identified "three strategic goals for which transformational scientific breakthroughs are urgently needed." [16] These goals include making fuels from sunlight (see **Figure 1**); generating electricity without carbon dioxide emissions (see **Figure 2**); and revolutionizing energy efficiency and use (see **Figure 3**).[17] The figures referenced provide an illustration of possible breakthrough research needs for each as identified by the BESAC subcommittee.

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[11] Testimony of Dr. Steven Chu, in U.S. Congress, House Committee on Science, *Should Congress Establish "ARPA-E", The Advanced Research Projects Agency - Energy?*, hearings, 109th Congress, 2nd sess., March 9, 2006, H.Hrg. 109-39 (Washington: GPO, 2006).

[12] John M. Broder and Matthew L. Wald, "Big Science Role Is Seen in Global Warming Cure," *New York Times*, February 12, 2009 at http://www.nytimes.com/2009/02/12/us/politics/12chu.html?_r=1.

[13] Ibid.

[14] Ibid.

[15] For more information on these activities and to obtain copies of the reports from the workshop and panels, see http://www.sc.doe.gov/BES/reports/list.html.

[16] Department of Energy, Basic Energy Sciences Advisory Committee, Subcommittee on Facing Our Energy Challenges in a New Era of Science, *New Science for a Secure and Sustainable Energy Future: A Report from the Basic Energy Sciences Advisory Committee*, December 2008 at http://www.sc.doe.gov/BES/reports/files/NSSSEF_rpt.pdf.

[17] Ibid.

Figure 1. Making Fuels From Sunlight

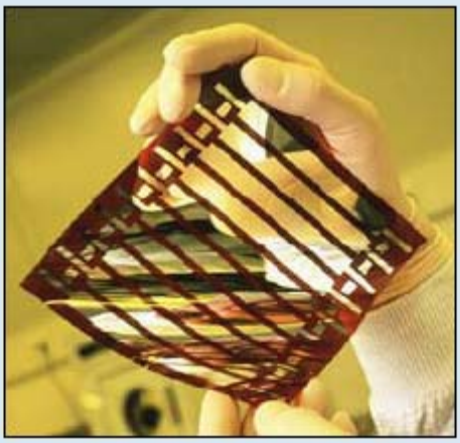
Illustration of Breakthrough Research Needs

Solar Power

Solar power is in rapid growth mode; new manufacturers and installers of photovoltaic solar cell systems are cropping up everywhere. With present technologies, even assuming continued rapid growth, solar cells are predicted to only supply about 5% of the huge amount of carbon-free energy we will need by 2050. The challenge for the United States is to produce solar power at a cost less than coal-based electricity–a factor of 10 better than we can do today.

Most present production of solar power is based on crystalline silicon cells, the first generation technology. The second generation, now starting to be commercialized, is based on thin-film cells and cells made from inexpensive oxide semiconductor materials coated with light sensitive dyes and from photoactive organic polymeric materials. These approaches may yield much lower costs, but at present have significantly lower conversion efficiencies.

The game-changing breakthrough needed from third generation cells is *both* lower cost and very high conversion efficiency. New paradigms for photon capture and conversion are needed to meet this goal. Presently, very high efficiency solar cells can be produced by combining different semiconductor materials in a tandem cell structure so as to capture far more of the energy in sunlight. However, the cost per unit area of these cells is 200 times more expensive than first generation cells. Basic research is necessary to maintain the high efficiency of tandem cells while lowering their cost by exploring new materials, novel structures, and the use of unique solar concentrators. Another approach to third generation solar cells is based on so-called quantum dot solar cells, made from semiconducting nanocrystals arranged in unique configurations that alter and enhance the absorptive and electron-producing properties of semiconductors like silicon in dramatic ways. Third generation solar cells are still in the early stages of scientific exploration and we don't know how to make cells that show the promised high efficiency and low cost sufficient to beat the cost of electricity from coal. However, the opportunity is huge; third-generation cells can in principle greatly exceed the theoretical limit of conversion efficiency for first and second-generation designs. Using new materials and hybrid designs, they can dramatically lower the cost of solar electricity.

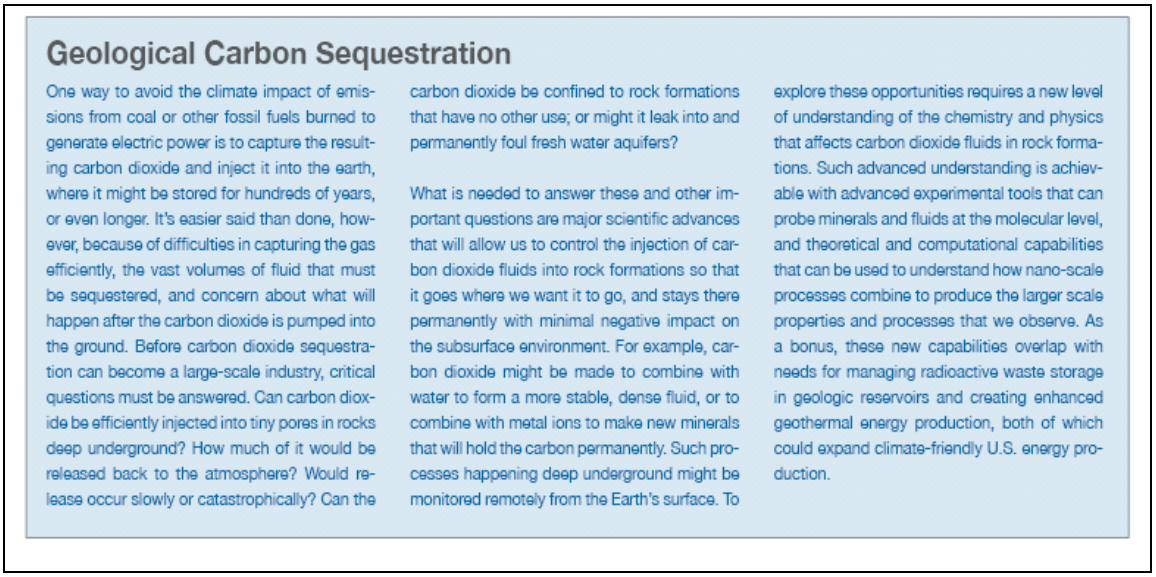


Organic materials promise inexpensive flexible solar fabric for powering personal electronics or for integration into buildings. Source: BES Solar Report, Konarka Technologies

Source: Department of Energy, Basic Energy Sciences Advisory Committee, Subcommittee on Facing Our Energy Challenges in a New Era of Science, *New Science for a Secure and Sustainable Energy Future: A Report from the Basic Energy Sciences Advisory Committee*, December 2008 at http://www.sc.doe.gov/BES/reports/files/NSSSEF_rpt.pdf.

Figure 2. Generating Electricity Without Carbon Dioxide Emissions

Illustration of Possible Breakthrough Research Needs



Geological Carbon Sequestration

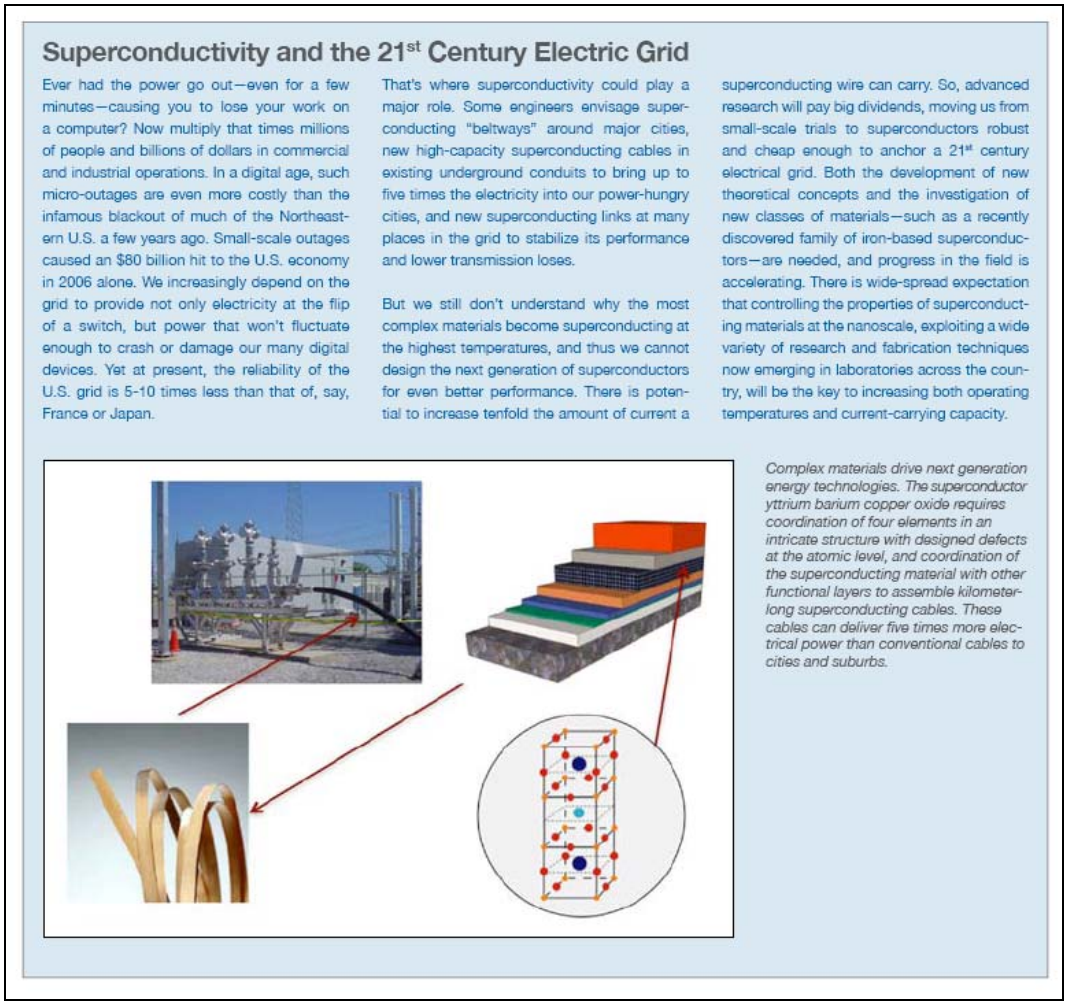
One way to avoid the climate impact of emissions from coal or other fossil fuels burned to generate electric power is to capture the resulting carbon dioxide and inject it into the earth, where it might be stored for hundreds of years, or even longer. It's easier said than done, however, because of difficulties in capturing the gas efficiently, the vast volumes of fluid that must be sequestered, and concern about what will happen after the carbon dioxide is pumped into the ground. Before carbon dioxide sequestration can become a large-scale industry, critical questions must be answered. Can carbon dioxide be efficiently injected into tiny pores in rocks deep underground? How much of it would be released back to the atmosphere? Would release occur slowly or catastrophically? Can the carbon dioxide be confined to rock formations that have no other use; or might it leak into and permanently foul fresh water aquifers?

What is needed to answer these and other important questions are major scientific advances that will allow us to control the injection of carbon dioxide fluids into rock formations so that it goes where we want it to go, and stays there permanently with minimal negative impact on the subsurface environment. For example, carbon dioxide might be made to combine with water to form a more stable, dense fluid, or to combine with metal ions to make new minerals that will hold the carbon permanently. Such processes happening deep underground might be monitored remotely from the Earth's surface. To explore these opportunities requires a new level of understanding of the chemistry and physics that affects carbon dioxide fluids in rock formations. Such advanced understanding is achievable with advanced experimental tools that can probe minerals and fluids at the molecular level, and theoretical and computational capabilities that can be used to understand how nano-scale processes combine to produce the larger scale properties and processes that we observe. As a bonus, these new capabilities overlap with needs for managing radioactive waste storage in geologic reservoirs and creating enhanced geothermal energy production, both of which could expand climate-friendly U.S. energy production.

Source: Department of Energy, Basic Energy Sciences Advisory Committee, Subcommittee on Facing Our Energy Challenges in a New Era of Science, *New Science for a Secure and Sustainable Energy Future: A Report from the Basic Energy Sciences Advisory Committee*, December 2008 at http://www.sc.doe.gov/BES/reports/files/NSSSEF_rpt.pdf.

Figure 3. Revolutionizing Energy Efficiency and Use

Illustration of Possible Breakthrough Research Needs



Source: Department of Energy, Basic Energy Sciences Advisory Committee, Subcommittee on Facing Our Energy Challenges in a New Era of Science, *New Science for a Secure and Sustainable Energy Future: A Report from the Basic Energy Sciences Advisory Committee*, December 2008 at http://www.sc.doe.gov/BES/reports/files/NSSSEF_rpt.pdf.

How Might ARPA-E Obtain Guidance on Customer Needs?

Although there may be interim steps along the way, some experts believe that the end goal for ARPA-E research is a "proof of concept," that is, "evidence (usually deriving from an experiment or pilot project) demonstrating that a design concept, business idea, etc., is feasible."[18] Although smaller in scale than ARPA-E, university proof of concept centers, whose goal is to accelerate the commercialization of university innovations without being part of the commercialization effort,

[18] Oxford English Dictionary at http://dictionary.oed.com/.

might provide a useful example for ARPA-E as to how to incorporate the views of customers into the research process.

A study by the Kauffman Foundation examined two proof of concept centers they deemed successful: the Massachusetts Institute of Technology (MIT) Deshpande Center for Technological Innovation and the University of California, San Diego (USCD) von Liebig Center.[19] MIT's Deshpande Center investment of $9.0 million since 2002 has resulted in 1 licensing agreement, 18 startup companies, $140 million in outside financing, and over 200 jobs.[20] UCSD's von Liebig Center project investment of $3.8 million since 2001 has resulted in 22 license agreements and 16 start-up companies, which have attracted more than $78 million in subsequent capital from the private sector and created over 130 new jobs.[21]

At MIT, business community volunteers called "Catalysts" provide guidance to researchers. The Catalyst volunteers are individuals with experience relevant to innovation, technology commercialization, and entrepreneurship, but do not represent any company interests. The approximately 50 Catalysts are chosen based on their "experience in commercializing early stage technologies and/or mentoring researchers and entrepreneurs, and industry expertise; willingness to proactively provide assistance to MIT research teams; willingness to abide by the time commitment, confidentiality, and conflict of interest guidelines; and commitment to the interests of MIT researchers and the Deshpande Center."[22] Catalysts are also members, along with MIT staff, of a multidisciplinary committee that evaluates all applications for research funds. Once selected by the committee, a Catalyst works with researchers to submit a full proposal.[23]

At UCSD's von Liebig Center, two kinds of mentors provide guidance to researchers: Technology and Business Advisors, and Champion Entrepreneurs. The approximately six Technology and Business Advisors are seasoned entrepreneurs, paid discounted wages by UCSD, to help project teams develop and implement commercialization strategies. Champion Entrepreneurs are venture capitalists, experienced entrepreneurs, and angel investors who lead projects through the commercialization pipeline and help start a company around it.[24] Advisors at UCSD are assigned to faculty after they submit a Statement of Intent to help them prepare a proposal and presentation to a review panel that consists of both technical and business experts. Projects are selected based on the technology's novelty and need, the potential market size, the market definition, the

[19] Christine Gulbranson and David Audretsch, *Proof of Concept Centers: Accelerating the Commercialization of University Innovation*, Ewing Marion Kauffman Foundation, January 2008 at http://sites.kauffman.org/pdf/POC_Centers_01242008.pdf.

[20] MIT Deshpande Center for Technological Innovation, "About the Center," webpage at http://web.mit.edu/deshpandecenter/about.html.

[21] UCSD von Liebig Center, "Mission," webpage at http://www.vonliebig.ucsd.edu/about/mission.shtml.

[22] MIT Deshpande Center for Technological Innovation, "Catalyst Program," webpage at http://web.mit.edu/deshpandecenter/catalyst.html. Christine Gulbranson and David Audretsch, *Proof of Concept Centers: Accelerating the Commercialization of University Innovation*, Ewing Marion Kauffman Foundation, January 2008 at http://sites.kauffman.org/pdf/POC_Centers_01242008.pdf.

[23] Christine Gulbranson and David Audretsch, *Proof of Concept Centers: Accelerating the Commercialization of University Innovation*, Ewing Marion Kauffman Foundation, January 2008 at http://sites.kauffman.org/pdf/POC_Centers_01242008.pdf.

[24] UCSD von Liebig Center, "Mentor a Project Team," webpage at http://www.vonliebig.ucsd.edu/giving/mentor.shtml.

technology's maturity, the utility of the grant, the intellectual property position, and the principal investigator's credibility.[25]

What Will Be ARPA-E's Relationship with Other DOE R&D Organizations and DARPA?

The America COMPETES Act mandates that ARPA-E be managed by a presidentially appointed director, confirmed by the Senate, who would report to the Secretary of Energy, presumably to facilitate the independence of ARPA-E within DOE. The act also states that no other programs within DOE will report to the ARPA-E director. As a result, the head of ARPA-E could not also be head of another organization such as the Office of Science or one of the energy technology offices, which focus on specific topics such as energy efficiency and renewable energy, fossil energy, nuclear energy, and electricity delivery and energy reliability. In addition, one key consideration that the ARPA-E director may face is to identify projects that complement those of the Office of Science and the energy technology offices.

Other DOE R&D Organizations

The Department of Energy may need to distinguish how ARPA-E's role differs from that of existing DOE R&D activities, including the Office of Science and the energy technology offices (see **Figure 4**). For example, DOE's Office of Science has now funded 46 new Energy Frontier Research Centers (EFRCs).[26] In addition, the Department of Energy is proposing to fund eight Energy Innovation Hubs as discussed in its FY2010 budget request. During congressional testimony, Secretary Chu provided a description of each of these initiatives and distinguished between them:

> Specifically, this budget request includes three initiatives designed to cover the spectrum of basic to applied science to maximize our chances of energy breakthroughs. The FY 2010 budget will launch eight Energy Innovation Hubs, while the Energy Frontier Research Centers (EFRCs) and ARPA-E were launched last month. Let me briefly explain the differences and why I believe launching these Hubs is so important.
>
> EFRCs are small-scale collaborations (predominantly at universities) that focus on overcoming known hurdles in basic science that block energy breakthroughs – not on developing energy technologies themselves.
>
> ARPA-E is a highly entrepreneurial funding model that explores potentially revolutionary technologies that are too risky for industry to fund.
>
> The proposed Energy Innovation Hubs will take a very different approach – they will be multi-disciplinary, highly collaborative teams ideally working under one roof to solve priority technology challenges, such as artificial photosynthesis (creating fuels from sunlight)....

[25] Christine Gulbranson and David Audretsch, *Proof of Concept Centers: Accelerating the Commercialization of University Innovation*, Ewing Marion Kauffman Foundation, January 2008 at http://sites.kauffman.org/pdf/POC_Centers_01242008.pdf.

[26] For more information, see http://www.er.doe.gov/bes/EFRC.html.

The following is additional information about the three initiatives:

• Energy Innovation Hubs

In FY 2010 the Department proposes to fund eight multi-disciplinary Energy Innovation Hubs, at a total of $280 million. Modeled after the Department's Bioenergy Research Centers, the work of the Hubs will span from basic research to engineering development to commercialization and a hand-off to industry. Each Hub will be funded at $25 million per year, with one-time additional start-up funding of $10 million in the first year for renovation, equipment and instrumentation.

The Hubs will support cross-disciplinary research and development focused on the barriers to transforming energy technologies into commercially deployable materials, devices, and systems. They will advance highly promising areas of energy science and technology from their early stages of research to the point that the risk level will be low enough for industry to deploy them into the marketplace.

While the intent is to provide a funding stream that is more dependable than the standard funding mechanisms, renewal after 5 years will not be automatic. To receive renewed funding, Hubs will be expected to be delivering exceptional scientific progress.

The research Hubs will explore the following topics: Solar Electricity; Fuels from Sunlight; Batteries and Energy Storage; Carbon Capture and Storage; Grid Materials, Devices, and Systems; Energy Efficient Building Systems Design; Extreme Materials; and Modeling and Simulation.

• Energy Frontier Research Centers

In FY 2010 the Department of Energy will continue to support Energy Frontier Research Centers (EFRC). Currently there are 46 EFRCs, funded at $2 to $5 million per year. These centers enlist the talents and skills of the very best scientists and engineers to address current fundamental scientific roadblocks to clean energy and energy security. Roughly one-third of the centers are supported by Recovery Act funding. These centers, involving almost 1,800 researchers and students from universities, national labs, industry, and non-profit organizations from 36 states and the District of Columbia, address the full range of energy research challenges in renewable and low-carbon energy, energy efficiency, energy storage, and cross-cutting science. EFRC researchers take advantage of new capabilities in nanotechnology, light sources that are a million times brighter than the sun, supercomputers, and other advanced instrumentation, much of it developed in collaboration with the Department of Energy's Office of Science.

• Advanced Research Projects Agency- Energy (ARPA-E)

ARPA-E is a new Department of Energy organization modeled after the Defense Advanced Research Projects Agency, created during the Eisenhower administration in response to Sputnik. The Recovery Act provided $400 million and the FY 2010 budget requests $10 million for ARPA-E. The purpose of ARPA-E is to advance high-risk, high-reward energy research projects that can yield revolutionary changes in how we produce, distribute, and use energy. It will ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies.

ARPA-E seeks out the best ideas and assembles teams that can move quickly to help bring the idea to market, and funds this work through grants that range between $500,000 and $10 million. Most projects will be funded with seed money that sunsets after three years.

> Research teams are expected to either make exceptionally rapid progress or bring their technology to the point the private sector can pick it up within that time.[27]

In addition, the America COMPETES Act authorizes the establishment of Discovery Science and Engineering Innovation Institutes, multidisciplinary research institutes located at DOE national laboratories that would apply fundamental science and engineering discoveries to technological innovations. No funding, however, has been provided for these institutes.[28]

Defense Advanced Research Projects Agency (DARPA)

One option to quickly begin ARPA-E's operations may be to take advantage of DARPA's Program Managers and energy portfolio. As illustrated in **Figure 5**, DARPA faces challenges that will be similar to those of ARPA-E in terms of focusing on mid-term programs, based on time of acquisition, relative to other DOD activities that focus on near and far-term programs. One analyst testified that the following are key elements in DARPA's succeeding in its unique role as an instigator of radical innovation:

- **Create surprise; don't just seek to avoid it**: DARPA mission is to investigate new emerging technological capabilities that have prospects to create disruptive capabilities. It is differentiated from other R&D organizations by a charter that explicitly emphasizes ''high-risk, high payoff'' research.

- **Build communities of ''change-state advocates''**: DARPA Program Managers may often themselves foster a specific concepts or technological approach that they seek to explore and develop. But they almost never are the main, let alone sole, investigator of the notion. Rather it is DARPA's motif to instigate cooperation among a group of forward-looking researchers and operational experts. In this sense, DARPA's success depends on it being a leader and catalyst in developing this community of interest.

- **Define challenges, develop solution concepts, and demonstrate them**: One aspect of DARPA's success has been efforts to define strategic challenges in detail. Since its inaugural Presidential Issues, DARPA has been problem focused, seeking breakthrough change-state approaches to overcome daunting issues.[29]

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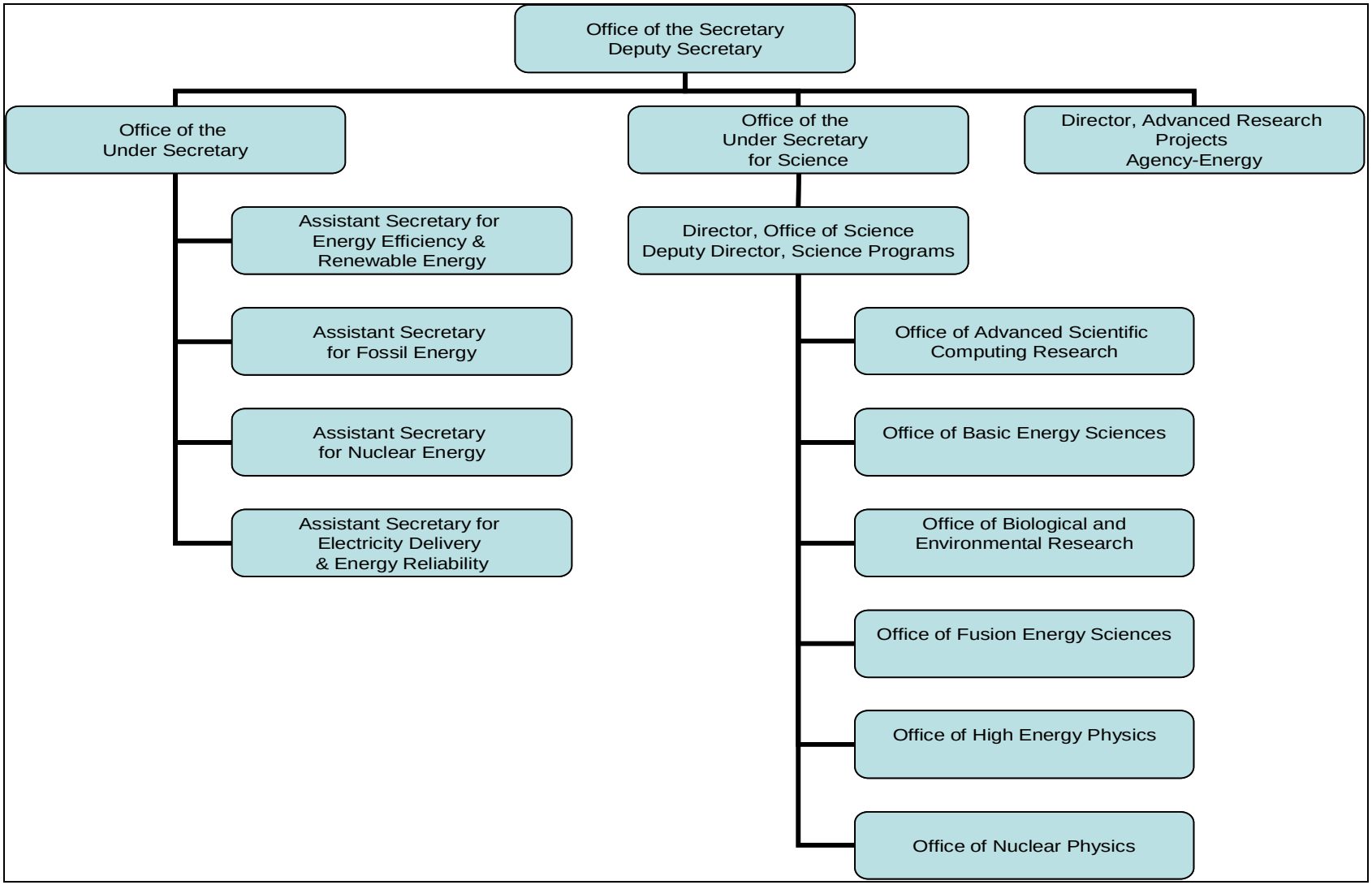
[27] Testimony of Secretary of Energy Steven Chu, *FY 2010 Appropriations Hearing*, Senate Committee on Appropriations Subcommittee on Energy and Water Development, and Related Agencies, May 19, 2009 at http://appropriations.senate.gov/Hearings/2009_05_19_-Energy-_Testimony_of_Secretary_Chu_at_May_19_Energy_and_Water_Subcommittee_Hearing.pdf?CFID=3770527&CFTOKEN=27868417.

[28] According to a personal communication between CRS and OSTP, the Obama Administration contends that Discovery Science and Engineering Innovation Institutes correspond with pre-existing Bioenergy Research Centers, SciDAC Institutes, and Energy Frontier Research Centers.

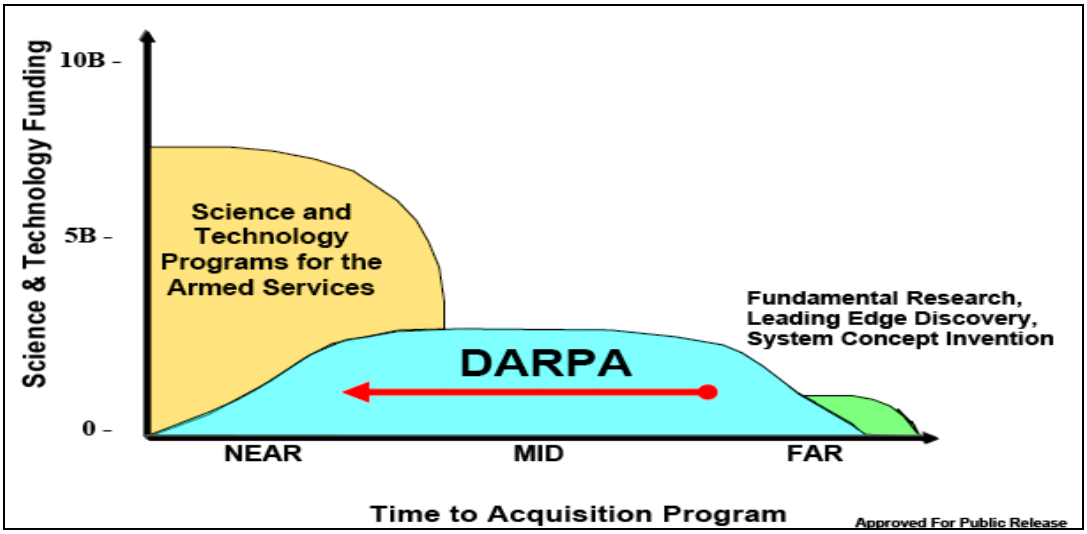
[29] Testimony of Richard Van Atta, Research Staff Member, Science & Technology Policy Institute, Institute for Defense Analyses in U.S. Congress, House Committee on Science and Technology, "Establishing the Advanced Research Projects Agency – Energy (ARPA-E) – HR 364," hearing, 110th Congress, 1st sess., April 26, 2007, H.Hrg. 110-22 at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_house_hearings&docid=f:34719.wais.pdf.

Figure 4. Selected Department of Energy Research and Development Organizations



Source: Congressional Research Service. Adapted from Department of Energy, Organization Chart, webpage at http://www.energy.gov/media/DOECHART-NONAMES-012209.pdf and http://www.er.doe.gov/about/Organization/Organization_chart/OneSC-org.pdf#page=1. Not all organizations are presented.

Figure 5. DARPA Role in Science and Technology



Source: Dr. Anthony J. Tether, DARPA Director, Defense Advanced Research Projects Agency, "PACOM S&T Conference: Defense Advanced Research Projects Agency PACOM S&T Conference," powerpoint presentation, 2008 at http://www.dtic.mil/ndia/2008POST/Wed1/Tether/tether.pdf.

Besides the management lessons that might be learned from DARPA's history of interacting with other DOD organizations to ensure programs are complementary, employing Program Managers, and its way of doing business (see **Box 3 below**), one policy option might be for ARPA-E to use some of DARPA's existing Program Managers focused on energy issues, or alternatively Program Managers who are ending their rotation at DARPA. This would provide ARPA-E with a workforce already trained in how to work as a Program Manager in the DARPA model. In addition, ARPA-E might either subsume DARPA's existing energy projects, or alternatively solicit the researchers its supports for ideas appropriate for ARPA-E.

DARPA includes energy programs within its portfolio. For example, in its 2007 strategic plan, DARPA identifies the following energy projects:

- Mobile Integrated Sustainable Energy Recovery (MISER) program: to develop technologies that can use military waste to run military generators;
- Very High Efficiency Solar Cell program: to develop photovoltaic devices with efficiencies exceeding 50 percent; and the
- BioFuels program: to develop an affordable surrogate for military jet fuel (JP-8) derived from oil-rich crops produced by either agriculture or aquaculture including, but not limited to, plants, algae, fungi, and bacteria.[30]

[30] DARPA, *Strategic Plan 2007* at http://www.darpa.mil/Docs/DARPA2007StrategicPlanfinalMarch14.pdf. A new strategic plan will be made available when the detailed FY2010 budget is released.

Box 3. Doing Business with DARPA Brochure

DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming our national security by sponsoring revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their military use. To achieve these goals, DARPA focuses on the following when crafting business agreements:

- Developing of innovative business relationships and practices
- Matching military requirements with technological opportunities
- Protecting information and ideas
- Creating agreements for investments in high-risk projects involving revolutionary technologies and systems
- Promoting innovation by creating flexible strategy agreements

Getting Your Ideas Considered by a DARPA Program Manager

Don't constrain your great ideas by how you think DARPA may react. Even though DARPA may not appear active in a particular area doesn't mean the Agency won't be interested in a great technological idea in a new arena. In fact, your idea could lead to new areas of research. The key to working with DARPA is through a Program Manager. To maintain an entrepreneurial atmosphere and the flow of new ideas, DARPA hires Program Managers for 2 to 6 years; the best way to foster innovations is to bring in new people with fresh outlooks. DARPA Program Managers:

- Provide feedback regarding whether an idea is suited to DARPA.
- Help shape ideas to synchronize with an ongoing or new DARPA program.
- In some cases, a Program Manager may substantially alter what he or she plans to do based on a new idea.

A big part of a Program Manager's job is to find great ideas upon which to build new programs. Information exchanges with DARPA Program Managers are the foundation for "Doing Business with DARPA." When considering an idea, DARPA Program Managers will ask:

- What are you trying to do?
- How is this done now? What are the limitations?
- How will this approach remove those limitations and improve performance? By how much?
- If an idea is successful, what difference will it make?

DARPA Program Managers often fund studies ("seedlings") as initial research to determine if a more formal program is appropriate.

DARPA Methods of Soliciting Business: DARPA uses requests for proposals (RFPs) and broad agency announcements (BAAs) to solicit business. Because DARPA understands that creating proposals involves a great deal of time and effort, many DARPA solicitations encourage the submission of a white paper or abstract to determine whether an idea is likely to be selected. It is the Program Manager's job to develop projects, so be sure to demonstrate how your idea will fit as part of a larger project.

Requests for Proposal (RFPs): An RFP provides a specific statement of work, contract deliverables, and evaluation criteria for Government selection. An RFP serves as the basis for award selection.

Broad Agency Announcements (BAAs): A BAA is a competitive solicitation procedure used to obtain proposals for basic and applied research and that part of development not related to the development of a specific system or hardware procurement. The type of research solicited under a BAA attempts to increase knowledge in science and/or to advance the state of the art compared to practical application of knowledge.

Evaluation and Award: BAA proposals are evaluated on technical merit and are not compared to other proposals. The basis for the selection of proposals is the technical importance with respect to Agency programs and funding availability. Cost realism and reasonableness is also considered, to the appropriate extent.

Source: Excerpts from DARPA, "Doing Business with DARPA," at http://www.darpa.mil/DoingBusiness.pdf.

One key difference between DARPA and ARPA-E as outlined in the America COMPETES Act may be the number of Program Managers relative to its overall budget. While DARPA's budget is $3 billion in FY2009 with approximately 100 Program Managers,[31] ARPA-E's budget is $400 million with the America COMPETES Act stating ARPA-E must have minimum of 70 scientific, engineering, and professional personnel. It is not yet known how many of the 70 will be Program Managers; however, the disparity of funding may mean that each Program Manager will have less funding to facilitate their ideas. This may make it challenging for ARPA-E to recruit high quality Program Managers and for those managers to be successful.

What Lessons Might be Learned from the Establishment of Other DARPA-based Organizations?

As discussed earlier, the general concept for management of ARPA-E is based on that of DARPA (see **Box 2 above**). Since 2002, two federal organizations have been established based on the DARPA model: the Homeland Security Advanced Research Project Agency (HSARPA) and the Intelligence Advanced Research Projects Activity (IARPA).

Homeland Security Advanced Research Project Agency (HSARPA)

The Homeland Security Act of 2002 (P.L. 107-296) authorized establishment of HSARPA with an authorization of $500 million for FY2003 and such sums as may be necessary thereafter. [32] According to the act, the HSARPA Director was to administer an Acceleration Fund for Research and Development of Homeland Security Technologies

> to award competitive, merit-reviewed grants, cooperative agreements or contracts to public or private entities, including businesses, federally funded research and development centers, and universities. The Director shall administer the Fund to
>
> (A) support basic and applied homeland security research to promote revolutionary changes in technologies that would promote homeland security;
>
> (B) advance the development, testing and evaluation, and deployment of critical homeland security technologies; and
>
> (C) accelerate the prototyping and deployment of technologies that would address homeland security vulnerabilities.

Some experts believe that although Congress provided HSARPA with a strong and flexible authorization closely modeled on DARPA's strengths, it has not been adequately utilized or implemented, emphasizing the need for congressional oversight of ARPA-E as it begins

[31] This estimate is based on a statement in the following article, Peter Lee and Randy H. Katz, *ReEnvisioning DARPA*, December 12, 2008 at http://www.cra.org/ccc/docs/init/Re-Envisioning_DARPA.pdf, and a review of DARPA's staff list at http://www.darpa.mil/Docs/staff-directory.pdf.

[32] For more information on HSARPA, see CRS Report RL34356, *The DHS Directorate of Science and Technology: Key Issues for Congress*, by (name redacted) and (name redacted).

operations.[33] Among the concerns are a minimal budget, lack of an initial director for approximately one year providing insufficient leadership for start-up in a competitive environment despite the presence of a talented staff, and lack of autonomy and flexibility in making award decisions.[34]

Given the proximity of its name to DARPA, and the statement in the act that HSARPA was "to promote revolutionary changes in technologies," most in the science and technology community believed that HSARPA would be based on the DAPRA model and would focus on innovative research.[35] According to its first director, however, comparisons of HSARPA to DARPA were inappropriate as only about 10 percent of HSARPA's work was comparable to that of DARPA.[36] By this statement, Dr. Bolka might have been implying that 10% of HSARPA's R&D was focused on transformative R&D, while 90% was focused on incremental R&D.[37]

This focus changed as HSARPA evolved. Beginning in 2006, DHS Under Secretary for Science and Technology Cohen redirected the work of HSARPA as part of a general reorganization of DHS' R&D activities. As a result, HSARPA began to focus its efforts on high risk and high reward transformative R&D research activities more similar to that of DARPA . HSARPA R&D focuses on two programs: Homeland Innovative Prototypical Solutions (HIPS), to demonstrate prototypes of high-payoff technologies in two to five years with moderate to high risk; and High Impact Technology Solutions (HITS), to conduct high-risk basic research that provides proofs of concept for potential breakthroughs.[38]

HSARPA is located within the Office of Innovation, whose overall budget was $33 million in FY2008. HSARPA's budget, therefore, is smaller than DARPA's ($2,959 million in FY2008).[39] In addition, HSARPA does not have a dedicated funding stream, which may influence its ability to be autonomous of its parent agency – a key aspect, some experts believe, of DARPA's success.

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[33] Testimony of William B. Bonvillian, , in U.S. Congress, House Committee on Science and Technology, "Establishing the Advanced Research Projects Agency – Energy (ARPA-E) – HR 364," hearing, 110th Congress, 1st sess., April 26, 2007, H.Hrg. 110-22 at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_house_hearings&docid=f:34719.wais.pdf.

[34] Ibid.

[35] American Association for the Advancement of Science, *Congress Finalizes Creation of Department of Homeland Security, Authorizes New S&T Infrastructure*, November 22, 2002 at http://www.aaas.org/spp/rd/dhs1122.pdf.

[36] David Bolka, HSARPA Director, as quoted in William New, "Homeland Security research agency has lofty vision," *Government Executive*, January 6, 2004 at http://www.govexec.com/story_page.cfm?articleid=27368&ref=rellink.

[37] According to the National Science Board (NSB), "Transformative research is defined as research driven by ideas that have the potential to radically change our understanding of an important existing scientific or engineering concept or leading to the creation of a new paradigm or field of science or engineering. Such research is also characterized by its challenge to current understanding or its pathway to new frontiers." This is less common than incremental research. As stated by the NSB, "The vast majority of scientific understanding advances incrementally, with new projects building upon the results of previous studies or testing long-standing hypotheses and theories. This progress is evolutionary—it extends or shifts prevailing paradigms over time. The vast majority of research conducted in scientific laboratories around the world fuels this form of innovative scientific progress." For more information, see National Science Board, *Enhancing Support of Transformative Research at the National Science Foundation*, May 2007 at http://www.nsf.gov/pubs/2007/nsb0732/nsb0732.pdf.

[38] CRS Report RL34356, *The DHS Directorate of Science and Technology: Key Issues for Congress*, by (name redacted) and (name redacted).

[39] For information on DARPA's budget, see http://www.darpa.mil/Docs/DARPAPB09February2008.pdf.

According to one expert, the failure to implement HSARPA as authorized illustrates several points for the implementation of ARPA-E that Congress should monitor:

- The innovation culture critical to success cannot be created by legislation alone unless the implementing agency shows real leadership, supports the new R&D mission, and is determined to use flexible statutory authorities to create a strong entity.
- An ARPA-E needs its own budget and the ability to control it, rather than taking its funding from other competitor agencies that will dispute the diversion
- An ARPA-E needs technical talent of great skill with leaders who also have experience at the helm of government R&D entities, and so can work with other agency bureaucracies
- An ARPA-E needs a clear mission—breakthrough technology or incremental technology (HSARPA tried both); mixing the two risks having the former become the billpayer for the latter.[40]

Intelligence Advanced Research Projects Activity (IARPA)

The Director of National Intelligence (DNI) established IARPA in 2007. It effectively began operation in February 2008 when its first director, Lisa Porter, began to manage the organization. IARPA is considered one of the DNI's mission support activities. According to IARPA, it does not have an operational mission by design, but rather "its focus is on capabilities that its user community might want in the future, not on the requirements they have today."[41] By user community, IARPA is referring to the Intelligence Community (IC), 16 federal organizations whose focus is national intelligence. [42]

The initial stages of IARPA might be a useful model to examine as ARPA-E begins its operations. Dr. Porter used the following management design elements in developing the IARPA organization:

- High-risk, high pay-off research with a clearly defined and measureable 3-5 year end-goal, rather than focusing on "quick wins" or "low hanging fruit";
- Autonomy from the IC's current activities, in order to challenge the status quo, but also complementary to existing IC activities rather than duplicating them;
- Best and brightest technical Program Managers, to identify the best ideas and the best performers to investigate those ideas, and who constantly rotate to continue to bring fresh ideas;
- Sufficient funding, so program mangers can invest in their ideas to see if they are successful, to incorporate possible failures, and to attract the best Program Managers;

[40] William B. Bonvillian, "Will the search for new energy technologies require a new R&D mission agency? – The ARPA-E debate," *bridges*, July 2007 at http://www.ostina.org/content/view/2297/.

[41] IARPA, "Organization," webpage at http://www.iarpa.gov/organization.html.

[42] For more information, see http://www.intelligence.gov/1-members.shtml.

- Flexibility, rather than specifying a particular organizational design;
- Full and open competition, including peer or independent review, to select the best projects;
- Customer involvement, so that the outcomes from IARPA's projects have a transition strategy to an end user; and
- Acceptance of low success rates, as long as the results are fully documented and the failure was not caused by lack of technical and programmatic integrity.[43]

IARPA uses the "Heilmeier Questions," developed by a former DARPA director to determine whether or not a good idea becomes an IARPA program:

> 1. What are you trying to do?
>
> 2. How does this get done at present? Who does it? What are the limitations of the present approaches? Are you aware of the state-of-the-art and have you thoroughly thought through all the options?
>
> 3. What is new about your approach? Why do you think you can be successful at this time? Given that you've provided clear answers to 1 and 2, have you created a compelling option? What does first-order analysis of your approach reveal?
>
> 4. If you succeed, what difference will it make? Why should we care?
>
> 5. How long will it take? How much will it cost? What are your mid-term and final exams? What is your program plan? How will you measure progress? What are your milestones/metrics? What is your transition strategy?[44]

IARPA has three strategic thrusts: Smart Collection, to dramatically improve the value of collected data; Incisive Analysis, to maximize insight from the information the IC collects in a timely fashion; and Safe and Secure Operations, to counter new capabilities of U.S. adversaries that could threaten the ability of the United States to operate effectively in a networked world. IARPA's budget is classified.

What Might Be the Next Steps in Establishing ARPA-E?

The following are the likely events needed to take place, not necessarily in this order, to establish ARPA-E and begin its operation based on the steps taken by IARPA when it began operation. Concerned members of Congress may be involved in oversight of these activities to ensure that ARPA-E meets the goals outlined in the America COMPETES Act.

- Nomination of ARPA-E Director by President Obama.

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[43] Personal Communication with Lisa Porter, Director, IARPA, January 23, 2009. Sally Adde, "Q&A With: IARPA Director Lisa Porter," *IEEE Spectrum*, May 2008 at http://www.spectrum.ieee.org/may08/6208. Yudhijit Bhattacharjee, "A New Spy Agency Asks Academics for Help in Meeting Its Mission," *Science*, January 9, 2009.

[44] IARPA, "It All Starts with the Heilmeier Questions," webpage, at http://www.iarpa.gov/join3.html.

- Conduct Senate hearing and vote on confirmation of ARPA-E Director.
- Identify location for ARPA-E operations, perhaps temporary until permanent space is determined.
- Employ senior administrative staff.
- Develop plan for ARPA-E operations including organization design, R&D initiatives, and related program offices.
- Recruit Program Managers suited to managing the program offices.
- Post pre-solicitation announcement for each program
- Host proposer's day for each program to familiarize participants with ARPA-E and its interest in a given program; promote an understanding of proposal submission requirements and process; and foster discussion of synergistic capabilities among potential program participants
- Soliciting proposals.
- Review proposals and make awards.

As stated by one expert, "Standing up new energy technologies is a major and complex challenge, perhaps the most difficult technology stand-up challenge we have faced. Ever."[45] If so, Congress might wish to ensure the implementation of ARPA-E meets the goals and principles provided in the America COMPETES Act.

Several management design elements to monitor include the timely appointment of a director for ARPA-E, recruitment of highly qualified technical Program Managers familiar with the DARPA process, maintenance of autonomy from DOE's current activities, and sufficient funding and organizational flexibility. In terms of the research funded, key aspects to monitor are the focus on high-risk, high-payoff, possibly transformational research that has clearly defined and measurable 3-5 year end-goals rather than incremental research or that focused on "quick wins;" full and open competition, so that the best projects are selected; and perhaps most challenging of all, customer involvement so that the outcomes from ARPA-E's projects have a transition strategy to an end user.

Activities in the 111th Congress

Besides the FY2009 appropriations activity described earlier and the likelihood that funding for the ARPA-E in FY2010 will be discussed by Congress, Members of Congress have introduced a number of bills that would impact ARPA-E:

- Title IV, entitled Energy Innovation and Workforce Development, of a draft Senate Committee on Energy and Natural Resources bill entitled America Clean Energy Leadership Act of 2009, would amend the America COMPETES Act to

[45] Testimony of William B. Bonvillian, , in U.S. Congress, House Committee on Science and Technology, "Establishing the Advanced Research Projects Agency – Energy (ARPA-E) – HR 364," hearing, 110th Congress, 1st sess., April 26, 2007, H.Hrg. 110-22 at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_house_hearings&docid=f:34719.wais.pdf.

give contracting authority to ARPA-E separate from the Department,[46] make technical corrections to reporting requirements, and authorize ARPA-E through 2020.[47] This bill was approved by the Senate Energy and Natural Resources committee on June 17, 2009.[48]

- The American Clean Energy and Security Act of 2009 (H.R. 2454),as passed by the House, would provide 1.05% of the cap and trade allowances from 2012 to 2050 to fund ARPA-E.[49] In addition, it would require that the Secretary of Energy coordinate the innovation activities of Clean Energy Innovation Centers, created by that proposed act, with ARPA-E, national laboratories, and EFRCs, and within industry, and to avoid duplication of research, by annually issuing guidance regarding national energy research and development priorities and strategic objectives; and convening a conference of DOE staff and others to share research results, program plans, and opportunities for collaboration.
- The American Conservation and Clean Energy Independence Act (H.R. 2227) would modify the strategic petroleum reserve and use funds generated as a result of this action to fund ARPA-E and a number of other energy-related activities.

Issues for Congress

Besides overseeing the establishment of ARPA-E and its funding, an issue for Congress is how ARPA-E will differ from existing DOE Office of Science activities, including the new Energy Frontier Research Centers, the DOE energy technology offices, and the Energy Innovation Hubs proposed in the FY2010 budget. In addition, several bills introduced in Congress would either provide ARPA-E with additional authority or a source of funds, or require the Secretary of Energy to monitor its interaction with other proposed DOE research and development organizations.

[46] For more information, see CRS Report RL34760, *Other Transaction (OT) Authority*, by (name redacted).

[47] For more information, see http://energy.senate.gov/public/index.cfm?FuseAction=IssueItems.Detail&IssueItem_ID=cd38563f-445e-4c75-9a70-94324136c99b&Month=3&Year=2009.

[48] For more information, see Senate Energy and Natural Resources, "Committee Reports Energy Bill," press release, June 17, 2009 at http://energy.senate.gov/public/index.cfm?FuseAction=PressReleases.Detail&PressRelease_id=a3fe85e3-8145-4b45-bb0b-1df967416a1f&Month=6&Year=2009&Party=0.

[49] For more information on this bill, see CRS Report R40643, *Greenhouse Gas Legislation: Summary and Analysis of H.R. 2454 as Reported by the House Committee on Energy and Commerce*, coordinated by (name redacted) and (name redacted).

Appendix. Legislative Origins and Policy Debates Prior to ARPA-E Authorization

The DARPA model has frequently been proposed as a structure for improving the management of federal R&D. For example, an "advanced civilian technology agency" was proposed in the 100th and 101st Congresses.[50] In 1992, an NAS report recommended that the government consider a civilian technology corporation or a civilian technology agency in limited areas including energy research.[51] In 1993, the Progressive Policy Institute made a similar proposal.[52] In 1992, presidential candidate Bill Clinton and Senator Al Gore proposed the creation of a civilian advanced research agency to support research on renewable technologies and renewable fuels.[53]

From 1977-2000, DOE had an Advanced Energy Projects (AEP) division to "explore the feasibility of novel, energy-related concepts that evolve from advances in basic research," and "high-risk, exploratory concepts which do not readily fit into an existing DOE program area but which could lead to applications that span scientific or technical disciplines."[54] In 1995, DOE placed AEP's activities under a new Computational and Technology Research program. This reorganization was formally stated in DOE's 1997 budget request. Funding for the program was reduced in FY1998 and FY1999, and the AEP program was terminated in FY2000.[55]

Legislative Origins in the 109th and 110th Congress

Against this historical backdrop, in October 2005, a committee of the NAS recommended the establishment of ARPA-E in its report *Rising Above the Gathering Storm.*[56] In November 2005, during the 109th Congress, House Minority Leader Pelosi released an innovation agenda that proposed to create a new DARPA-like initiative within DOE.[57] In 2007, this same concept was part of an updated "Innovation Agenda" proposed by then Speaker of the House Pelosi at the beginning of the 110th Congress.[58]

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[50] Proposals during the 101st Congress, 2nd session, included S. 1978, H.R. 3833, H.R. 4715, and S. 2765. These are discussed in U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing*, OTA-ITE-443 (Washington, DC: GPO), February 1990.

[51] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *The Government Role in Civilian Technology: Building a New Alliance* (Washington, DC: National Academy Press, 1992).

[52] Will Marshall and Martin Schram, *Mandate for Change* (New York: Berkeley Books, 1993).

[53] Bill Clinton and Al Gore, *Putting People First: How We Can All Change America* (New York: Random House, 1992).

[54] Department of Energy, "Advanced Energy Projects: FY 1995 Research Summaries," DOE/ER-0660T, September 1995 at http://www.sc.doe.gov/bes/archives/summaries/Advanced_Energy_Projects_Summary_Book_FY1995.pdf. Sarah Adee, "Power Up," IEEE Spectrum, September 2007 at http://spectrum.ieee.org/sep07/5484.

[55] A history of this organization is at http://www.sc.doe.gov/bes/BES_history.html.

[56] The National Academies, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Washington, DC: National Academy Press, 2007), p. 154. This report was initially released in pre-publication form in October 2005.

[57] U.S. Congress, Office of Congresswoman Nancy Pelosi, "Pelosi: Unveils Innovation Agenda, Part of Vision for a Stronger America," press release, November 15, 2005, at http://www.house.gov/pelosi/press/releases/Nov05/innovation.html.

[58] U.S. Congress, Speaker Nancy Pelosi, *The Innovation Agenda: 110th Congress* at http://www.speaker.gov/issues?id=0016, April 27, 2007.

Although some analysts questioned whether ARPA-E was the best policy option to respond to the nation's energy challenges,[59] the proposal recommended in the NAS report became the basis for congressional hearings and debates in the 109th and 110th Congresses and eventually served as the outline for ARPA-E as authorized in the America COMPETES Act.

Policy Debates

In the 109th Congress, the Senate Committee on Energy and Natural Resources and the House Committee on Science held hearings on ARPA-E.[60] Chairman of the House Committee on Science Boehlert stated that he was an "open-minded skeptic" regarding ARPA-E, and pointed out that the recommendation for its establishment was based on four assumptions that he considered questionable:

- The problem with the energy market is that the supply of new technologies is insufficient;
- The supply of new technologies is constrained because of a lack of fundamental research;
- A sensible way to promote more fundamental research is to apply the DARPA model to a civilian energy sector; and
- Implementing the DARPA model is the best way to improve energy research, given tight federal budgets.[61]

In the 110th Congress, Chairman of the House Committee on Science and Technology Gordon held a similar hearing. In his opening statement, Chairman Gordon stated that, among several policy goals and objectives, DARPA has succeeded largely because it continued to foster a culture of innovation. The key for ARPA-E success, he said, is that it be a similarly nimble organization with minimal administrative layers and the ability to quickly start and stop research programs. According to the chair, "Investment in ARPA-E must be seen as the first step in boosting energy research and development to a level that addresses the scale of our challenge, and the true cost of doing transformational research."[62]

The following sections discuss several key questions debated during the House Science and Technology and Senate Committee on Energy and Natural Resources hearings held regarding ARPA-E in the 109th and 110th Congress.[63] This analysis incorporates issues discussed in hearing

[59] See for example, David Goldston, "Misspent Energy," *Nature*, 447:130, May 10, 2007 at http://www.nature.com/nature/journal/v447/n7141/pdf/447130a.pdf.

[60] U.S. Congress, Senate Committee on Energy and Natural Resources, "PACE Energy Act," hearing, 109th Cong., 2nd session, February 15, 2006 (Washington, DC: GPO, 2006) at http://www.gpoaccess.gov/chearings/index.html; U.S. Congress, House Committee on Science, "Should Congress Establish 'ARPA-E,' The Advanced Research Projects Agency - Energy?," hearing, 109th Congress, 2nd session, March 9, 2006 (Washington: GPO, 2006) at http://www.gpoaccess.gov/chearings/index.html.

[61] U.S. Congress, House Committee on Science, "Should Congress Establish 'ARPA-E,' The Advanced Research Projects Agency - Energy?," hearings, 109th Congress, 2nd session, March 9, 2006 (Washington, DC: GPO, 2006) at http://www.gpoaccess.gov/chearings/index.html.

[62] U.S. Congress, House Committee on Science and Technology Committee, "Establishing the Advanced Research Projects Agency-Energy (ARPA-E)," hearing, 110th Cong., 1st session, April 26, 2007, at http://www.gpoaccess.gov/chearings/index.html.

[63] U.S. Congress, Senate Committee on Energy and Natural Resources, "PACE Energy Act," hearing, 109th Cong., 2nd (continued...)

charters, Members' statements and questions, and the statements and responses of those providing expert testimony.

Is ARPA-E Needed?

Is ARPA-E needed when the federal government and industry already invest a great deal in energy R&D? Similarly, is a DARPA model the best research and development policy option for the energy marketplace? A related question is whether In-Q-Tel,[64] the Central Intelligence Agency (CIA) venture capital firm that provides funding to identify, develop, and deliver technologies of interest to the intelligence community, is a better model for the energy marketplace than DARPA. (See **Box 4 below**.)

Proponents state that ARPA-E will address organizational problems[65] at DOE by being small and flexible, unlike existing DOE organizations, which they believe are risk-averse and do not sufficiently interact with each other to reach the nation's energy goals. In addition, proponents argue that ARPA-E should focus on breakthrough research, using emerging basic research in areas such as nanotechnology to develop totally new technologies, as opposed to existing programs that have already identified paths forward and tend to focus on incremental advances. Further, unlike current programs, ARPA-E is designed to bridge the gap between basic research and industrial development—not to get products to the marketplace, but to transform the marketplace by accelerating research.

In response to the claim that ARPA-E will be more flexible and less risk-adverse, critics point out that the new organization will still be within DOE, so there is no guarantee that DOE management will let it take more risks than existing programs. While proponents contend that ARPA-E would bridge the gap between basic research and industrial development and that existing applied programs tend to focus on incremental advances, some critics argue that reforming DOE's existing programs would be better than creating a new organization.

Advocates for ARPA-E indicated that candidate energy technologies are not yet at a stage where venture capital investment, such as occurs with In-Q-Tel, would provide the best return. At some point, however, ARPA-E research may lead to technologies appropriate for venture capital investment. At that stage, it might be appropriate to incorporate a venture capital component into

(...continued)

session, February 15, 2006 (Washington, DC: GPO, 2006) at http://www.gpoaccess.gov/chearings/index.html; U.S. Congress, House Committee on Science, "Should Congress Establish 'ARPA-E,' The Advanced Research Projects Agency - Energy?," hearings, 109th Congress, 2nd session, March 9, 2006 (Washington: GPO, 2006) at http://www.gpoaccess.gov/chearings/index.html; U.S. Congress, House Committee on Science and Technology Committee, "Establishing the Advanced Research Projects Agency-Energy (ARPA-E)," hearing, 110th Cong., 1st session, April 26, 2007 (Washington, DC: GPO, 2007) at http://www.gpoaccess.gov/chearings/index.html.

[64] For more information on In-Q-Tel, see http://www.inqtel.org/.

[65] For example, a recent Brookings Institution study states that the magnitude of federal research efforts is inadequate and that "The character and format of federal energy efforts is also holding back innovation and rapid deployment of clean energy technology. In this connection, today's federal energy research program lacks the mission, capacity, and organizational structure to equip the nation to meet the full run of its challenges." James Duderstadt, Gary Was, Robert McGrath, Mark Muro, Michael Corradini, Linda Katehi, Rick Shangraw, and Andrea Sarzynski, *Energy Discovery-Innovation Institutes: A Step Toward America's Energy Sustainability*, Brookings Institution, February 2009 at http://www.brookings.edu/reports/2009/0209_energy_innovation_muro.aspx.

ARPA-E's design. Just as DARPA has evolved over 50 years, ARPA-E may need to evolve as well, some witnesses said.

Box 4. In-Q-Tel Management Design Keys

In 2001, a panel of the Business Executives for National Security (BENS) conducted an analysis of the In-Q-Tel model. It found that In-Q-Tel has the following characteristics that differentiate it from the typical business-as-usual federal R&D model. In-Q-Tel

- Can make equity investments;
- Has fewer bureaucratic constraints;
- Is not required to comply with the Federal Acquisition Regulations (FAR) requirements;
- Can obligate funds in multi-year increments, i.e., "no year" money;
- Is not restricted by civil service personnel policies;
- Engages only in unclassified projects;
- Has the cachet of being associated with the CIA; and
- Has a flexible deal structure modeled after commercial contractual/investment vehicles.

The BENS panel also described the differences between the In-Q-Tel model and a private venture capital firm. In-Q-Tel, BENS states, is better described as a "technology accelerator" than a venture capital firm, as In-Q-Tel

- Places its value proposition on obtaining IT [information technology] solutions, not foremost on return on equity or asset;
- Deals always result in a product or service (e.g., feasibility assessment, test product or prototype);
- Investments are more likely to provide value to the portfolio companies beyond cash: Investment is "smart money" in its portfolio companies; that is, In-Q-Tel provides portfolio companies with intellectual capital, technology-related experience and the Agency as a potential test-bed; and
- Due diligence process is more strict: In-depth investigation into the company's structure and financial status as well as the ability of the proposed technology to meet the Agency problem domain is completely evaluated before forming a contract.

The BENS panel found that "In-Q-Tel's potential advantage to the CIA outweighs the risk. In-Q-Tel should continue as the CIA's entrepreneurial and innovative venture facilitating the delivery of new technology to the CIA."

Source: Business Executives for National Security, *Accelerating the Acquisition and Implementation of New Technologies for Intelligence: The Report of the Independent Panel on the Central Intelligence Agency In-Q-Tel Venture*, June 2001 at http://www.bens.org/mis_support/nqtel-panel-rpt.pdf.

How Much Funding Should ARPA-E Receive? How Might ARPA-E Receive Funding?

The America COMPETES Act authorized $300 million for FY2008, and "such sums as necessary" for FY2009 and FY2010. The NAS report proposed that funding for ARPA-E start at $300 million the first year and increase gradually over five or six years to $1 billion per year. At that point, the program's effectiveness would be evaluated and appropriate actions taken, according to the report.

One issue discussed in hearings was whether the level of authorized funding for ARPA-E is sufficient to support the research necessary for ARPA-E to reach its goals. Some noted with concern that the proposed $300 million in FY2008 was less than 0.02% of the transportation and energy industries' annual revenues, a level they believed was insufficient relative to the potential

return. Some suggested that if it is to be successful, ARPA-E needs to be funded at a level comparable to DARPA—about $3 billion per year.[66]

Some of those testifying did not believe ARPA-E should be funded due to budget constraints. ARPA-E, they argued, would be funded by shifting resources from DOE's Office of Science. Increasing funding for the DOE Office of Science is also a goal of the America COMPETES Act. Some hearing witnesses expressed concern that dilution of DOE Office of Science resources might influence DOE's acceptance of ARPA-E, and hinder its success. Supporters of ARPA-E agreed that funding for the DOE Office of Science is the highest priority and testified that funding for ARPA-E should not be redirected from that office.

Some witnesses expressed concerns that a risk-tolerant agency like ARPA-E could not survive if it was subject to the annual appropriations cycle, political and financial pressures, and resource fluctuations that might stifle innovation. To overcome this potential challenge, some policymakers and experts have proposed funding ARPA-E outside of the regular appropriations process. This might include, for example, providing an advance appropriation supporting ARPA-E for several years, rather than the usual one-year appropriation. Another option is to identify a dedicated revenue source for ARPA-E. Some of the funding sources that have been proposed are

- oil industry tax and other incentives;[67]
- gasoline tax;[68]
- oil company profit tax;[69]
- federal oil and gas royalties;[70]
- climate change cap-and-trade program;[71] and

[66] DARPA's FY2008 budget is $3.0 billion. Its FY2009 request is $3.3 billion. For more information, see http://www.darpa.mil/body/budg.html.

[67] House Committee on Science and Technology, "Chairman Gordon Presses Establishment of ARPA-E as a Key to Clean Energy Independence," press release, May 9, 2008, at http://science.house.gov/press/PRArticle.aspx?NewsID=2189. As stated in the press release, "Four times in this Congress, the House has voted to repeal between $13 billion and $18 billion in tax and other incentives for the oil industry," Chairman Gordon said. "I don't disagree that we need incentives to move toward energy independence. But I don't believe the Federal government should be subsidizing an industry that is already seeing the highest profits on record. With oil at $125 a barrel and oil company profits at $123 billion last year alone, I think this $18 billion would be much better used to invest in the very goals and technologies that we are talking about today – ARPA-E, renewable energy, energy efficiency, and clean coal."

[68] For more information on the federal excise tax on gasoline, see CRS Report RL30304, *The Federal Excise Tax on Gasoline and the Highway Trust Fund: A Short History*, by (name redacted).

[69] For more information on use of oil company profits, see CRS Report RL34044, *The Use of Profit by the Five Major Oil Companies*, by (name redacted).

[70] Testimony of Melanie Kenderdine, Vice President, Gas Technology Institute in U.S. Congress, House Committee on Science, "Should Congress Establish ARPA-E, The Advanced Research Projects Agency - Energy?," hearings, 109th Congress, 2nd session, March 9, 2006, H.Hrg. 109-39 (Washington: GPO, 2006) at http://science.house.gov/commdocs/hearings/full06/March%209/Kenderdine.pdf. For an example of oil and gas royalties, see CRS Report RS22567, *Royalty Relief for U.S. Deepwater Oil and Gas Leases*, by (name redacted).

[71] Testimony of Melanie Kenderdine, Vice President, Gas Technology Institute in U.S. Congress, House Committee on Science, "Should Congress Establish ARPA-E, The Advanced Research Projects Agency - Energy?," hearings, 109th Congress, 2nd session, March 9, 2006, H.Hrg. 109-39 (Washington: GPO, 2006) at http://science.house.gov/commdocs/hearings/full06/March%209/Kenderdine.pdf. For more information on cap-and-trade programs, see CRS Report RL33846, *Greenhouse Gas Reduction: Cap-and-Trade Bills in the 110th Congress*, by (name redacted), (name red acted), and (name redacted).

- Strategic Petroleum Reserve funds.[72]

An analogous situation might be research supported through the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Program,[73] authorized by the Energy Policy Act of 2005 (P.L. 109-58), which receives funding of $50 million per year derived from royalties, rents, and bonuses from federal onshore and offshore oil and gas leases.[74] Based on past experience, however, all of these proposals would face challenges in Congress.

Will ARPA-E Work?

Some critics believe that what is preventing the United States from reaching its energy goals is not federal funding for innovative, high-risk research, but rather a lack of private-sector investment in basic research, failure to effectively transfer new energy technologies to the marketplace, or some combination of these. They point out the lack of a captive customer as a challenge to ARPA-E's ability to be successful: energy has a broad and diverse public and private market, while DARPA has DOD as its single primary customer, guaranteeing a solid base of demand. ARPA-E proponents indicated that ARPA-E is needed for "translational research." This type of research identifies the most pressing market needs, selects and funds the most promising scientific approaches to enable breakthrough products, and brings the best candidates of those products to the brink of production.

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[72] For more information on the strategic petroleum reserve, see CRS Report RL33341, *The Strategic Petroleum Reserve: History, Perspectives, and Issues*, by (name redacted).

[73] For more information, see http://www.fossil.energy.gov/programs/oilgas/ultra_and_unconventional/index.html.

[74] For more information, see CRS Report RL33493, *Outer Continental Shelf: Debate Over Oil and Gas Leasing and Revenue Sharing*, by (name redacted).

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