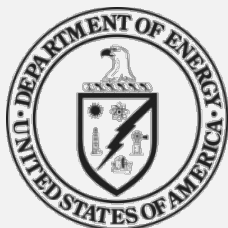




Advanced Research Projects Agency • Energy

Strategic Vision 2013



**Report to Congress
October 2013**

United States Department of Energy
Washington, DC 20585

Message from the Deputy Director

The Advanced Research Projects Agency-Energy (ARPA-E) catalyzes and accelerates energy technologies that will enhance the economic and energy security of the United States through the development of transformational technologies that reduce the America's dependence on energy imports; reduce energy related emissions; improve energy efficiency across all sectors of the economy; and ensure the United States maintains a technological lead in developing and deploying advanced energy technologies. ARPA-E advances high-potential, high-impact energy technologies that are too early for private sector investment and could lead to entirely new ways to generate, store, and use energy. It is important to note that the Agency's missions are not mutually exclusive. Programs and projects supported by ARPA-E normally address most or all of these missions in order to accelerate American creation of transformative energy technologies. These technologies allow for the development of safe and responsible domestic energy and promote the administration's goal of U.S. global leadership in the clean energy economy.

Pursuant to statutory requirements, this report is being provided to the following Members of Congress:

- **The Honorable Fred Upton**
Chairman, House Committee on Energy and Commerce
- **The Honorable Henry Waxman**
Ranking Member, House Committee on Energy and Commerce
- **The Honorable Lamar Smith**
Chairman, House Committee on Science, Space and Technology
- **The Honorable Eddie Bernice Johnson**
Ranking Member, House Committee on Science, Space and Technology
- **The Honorable Cynthia Lummis**
Chairwoman, Subcommittee on Energy
House Committee on Science, Space and Technology
- **The Honorable Eric Swalwell**
Ranking Member, Subcommittee on Energy
House Committee on Science, Space & Technology
- **The Honorable Hal Rogers**
Chairman, House Committee on Appropriations
- **The Honorable Nita M. Lowey**
Ranking Member, House Committee on Appropriations

- **The Honorable Rodney P. Frelinghuysen**
Chairman, Subcommittee on Energy and Water Development,
House Committee on Appropriations
- **The Honorable Marcy Kaptur**
Ranking Member, Subcommittee on Energy and Water Development,
House Committee on Appropriations
- **The Honorable Ron Wyden**
Chairman, Senate Committee on Energy and Natural Resources
- **The Honorable Lisa Murkowski**
Ranking Member, Senate Committee on Energy and Natural Resources
- **The Honorable Al Franken**
Chairman, Subcommittee on Energy,
Senate Committee on Energy and Natural Resources
- **The Honorable James E. Risch**
Ranking Member, Subcommittee on Energy,
Senate Committee on Energy and Natural Resources
- **The Honorable Barbara A. Mikulski**
Chairwoman, Senate Committee on Appropriations
- **The Honorable Richard C. Shelby**
Ranking Member, Senate Committee on Appropriations
- **The Honorable Dianne Feinstein**
Chairman, Senate Subcommittee on Energy and Water Development,
Senate Committee on Appropriations
- **The Honorable Lamar Alexander**
Ranking Member, Subcommittee on Energy and Water Development,
Senate Committee on Appropriations

If you have any questions or need additional information, please contact me or Mr. Brad Crowell, Acting Assistant Secretary for Congressional and Intergovernmental Affairs at 202-586-5450.

Sincerely,



Cheryl Martin
Deputy Director
Advanced Research Projects Agency — Energy (ARPA-E)

ADVANCED RESEARCH PROJECTS AGENCY - ENERGY STRATEGIC VISION 2013

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This report is in response to the requirements set forth in the America COMPETES Act, Public Law 110-69, section 5012(g)(2)(2007) as amended, which has been codified as 42 U.S.C. § 16538 (h)(2), wherein it is stated: “...the Director shall provide to the relevant authorizing and appropriations committees of Congress a roadmap describing the strategic vision that ARPA-E will use to guide the choices of ARPA-E for future technology investments over the following 3 fiscal years.”

I. OVERVIEW & HISTORY

The Advanced Research Projects Agency-Energy (ARPA-E) catalyzes transformational energy technologies that could create a more secure and affordable American future by advancing high-potential, high-impact energy technologies that are too early for private sector or other DOE applied research and development investment.

ARPA-E focuses on energy technologies that can be meaningfully advanced with a small investment over a defined period of time. ARPA-E’s rigorous program design, competitive project selection process, and hands-on engagement, ensure thoughtful expenditures while empowering America’s energy researchers with funding, technical assistance, and market awareness.

ARPA-E was established by the America COMPETES Act of 2007 following a recommendation by the National Academies in the *Rising above the Gathering Storm* report. As of March 2013, ARPA-E has funded 285 projects, across 33 states, with \$770 million in funding. These projects have been selected via 14 focused programs and two open solicitations. Approximately 38% of funding for projects has gone to small business, 35% to universities, 19% to large businesses, 6% to national labs, and 3% to non-profits. This distribution is reflective of both the applications received by the Agency and of the types of multi-disciplinary, multi-institutional teams that are most effective in developing transformative energy technologies.

II. ARPA-E MODEL

ARPA-E is modeled on the successful Defense Advanced Research Projects Agency (DARPA) and has created a unique, nimble, and adaptive structure that allows the Agency to quickly develop and execute programs, recruit a highly talented and experienced technical team, and provide awardees with technical assistance and market awareness to help projects succeed.

The core of the ARPA-E model is the team, particularly the Agency’s program directors and technology-to-market advisors. ARPA-E program directors provide awardees with technical guidance that combines scientific expertise and real-world experience, while ARPA-E

technology-to-market advisors supply awardees with critical business insight and strategies to move technologies toward the market. ARPA-E recruits program directors and technology-to-market advisors from diverse backgrounds including academia, industry, and national labs, all of whom are leaders in their fields and come to ARPA-E for limited, three- to four-year, terms. These limited terms instill a sense of urgency to succeed and regularly provide a fresh perspective on technologies and current market conditions.

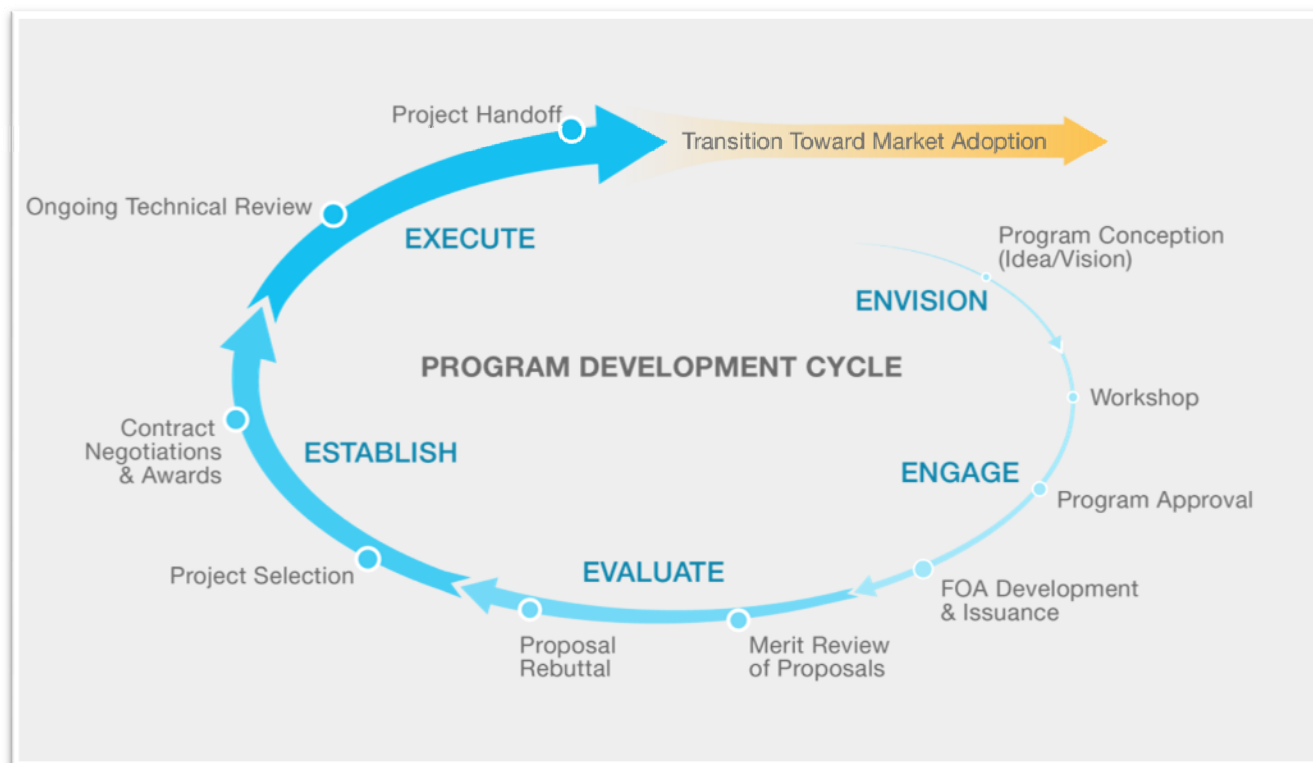
To ensure that program directors are able to maximize the impact of a limited term, and to give ARPA-E the agility to move into new technical areas and quickly react to changes in the market, ARPA-E has streamlined the program development and awards process. ARPA-E awards are selected through two models: “focused” programs, which are developed by program directors to address a specific energy challenge; and “open” solicitations, which seek applications for any idea that has the potential to produce game-changing breakthroughs in energy technology. ARPA-E encourages interdisciplinary thinking for both “open” solicitations and “focused” programs by recommending the use of a diverse combination of skills and partners that can approach challenges in new ways.

ARPA-E “focused” programs provide a unique bridge from basic science to early stage technology. These programs draw from the latest scientific discoveries and envision a viable path to commercial implementation through firm grounding in the economic realities and changing dynamics of the marketplace. For example, ARPA-E’s *Methane Opportunities for Vehicular Energy* (MOVE) program was created to develop technologies to utilize abundant domestic natural gas as fuel for passenger vehicles, while the *Rare Earth Alternatives in Critical Technologies* (REACT) program was developed as a rapid response to the disruption in the rare earth supply chain.

The concept for a new “focused” program is developed through engagement with diverse science and technology communities, including some that may not have traditionally been involved in the topic area, and by examining lessons learned from current ARPA-E programs and projects. For example, ARPA-E’s *Robust Affordable Next Generation Energy Storage* (RANGE) program was influenced by breakthroughs from the *Grid-Scale Rampable Intermittent Dispatchable Storage* (GRIDS) program. The program development cycle also involves careful comparison of ongoing research and development efforts in other Department of Energy program offices and industry. For instance, the *Green Electricity Network Integration* (GENI) program, which is modernizing the way electricity is transmitted, has been closely coordinated with other Department of Energy elements working on grid modernization, along with industry stakeholders.

The ARPA-E program development cycle is primarily about identifying gaps where high-impact, high-potential investment by ARPA-E could lead to transformational technologies enabling entirely new ways to generate, store, and use energy. New programs are carefully constructed

by program directors, working in an environment of constructive criticism where every aspect of a proposed program is intensely scrutinized for technical and economic viability, as well as impact on ARPA-E's mission.



ARPA-E also ensures that potentially transformational ideas outside the scope of existing “focused” programs are not lost by utilizing “open” funding opportunity announcements. Projects selected under the “open” solicitations pursue novel approaches to energy innovation, and work to meet technical needs not addressed by other parts of ARPA-E, the Department of Energy, or the private sector. In September 2013, ARPA-E also began utilizing *Innovative Development in Energy-Related Applied Science* (OPEN IDEAS), a rolling open solicitation that will allow ARPA-E to quickly support innovative applied energy research that has the potential to lead to new focused programs.

A key component of the ARPA-E model is hands-on engagement with awardees. Each ARPA-E project includes clearly defined technical and commercial milestones that awardees are required to meet throughout the life of a project. Program directors work closely with each awardee, through regular meetings and on-site visits, to ensure that milestones are being achieved in a timely fashion. When a project is not achieving the goals of the program, ARPA-E works with the awardee to rectify the issue or, in cases where the issue cannot be corrected, ARPA-E discontinues funding for the project. To ensure the efficiency of ARPA-E's hands-on engagement

with awardees, ARPA-E has in-house legal, procurement, and contracting staff, co-located with the program directors to provide direct access and timely communication.

The final element of the ARPA-E model is the technology-to-market program. The ARPA-E technology-to-market program provides awardees with practical training and critical business information to equip projects with a clear understanding of market needs to guide technical development and help projects succeed. Awardees are required to provide a technology-to-market plan prior to receiving an award and work closely with ARPA-E's technology-to-market advisors throughout the project, developing custom strategies to move projects toward the marketplace. In addition, ARPA-E facilitates relationships with investors, government agencies, small and large companies, and other organizations that are necessary to move awardees to the next stage of their project development.

The success of ARPA-E programs and projects will ultimately be measured by impact in the marketplace. As the projects ARPA-E funds seek to generate transformational energy technologies that do not exist today, ARPA-E looks at various metrics to measure progress towards eventual market adoption. The primary metrics are the individual project and program milestones, which are reviewed quarterly, while more broadly, technical success is measured by indicators such as patents and publications. Most importantly, ARPA-E gauges success by the creation of communities and project handoffs, including the formation of new companies and fostering public and private partnerships to ensure projects continue to move towards the market.

III. STRATEGIC VISION & MISSION IMPLEMENTATION

The mission of ARPA-E is to catalyze and accelerate the creation of transformational energy technologies by making investments in the early stages of development. By definition, the Agency is not bound by traditional technology development roadmaps. To the contrary, ARPA-E works "off roadmap" to quickly leverage new scientific breakthroughs and market developments. ARPA-E explores uncharted territories of energy technology and the intersections of those territories in order to create options for entirely new paths to accelerate the pace of innovation. ARPA-E uses a set of simply asked, but not always easily answered, questions to frame new programs (see "ARPA-E Program Framing Questions" below). The most critical question is the simplest of all: "If it works, will it matter?" This is an overarching principle that guides all of ARPA-E's investments.

ARPA-E Program Framing Questions

- What is the problem to be solved? Is the problem stated clearly so it is easily understood?
- If successful, how will the proposed program impact one or more of ARPA-E's mission areas: reducing imported energy, enhancing energy efficiency, and reducing energy-related emissions?
- What are the program goals and how will progress towards those goals be measured?
- What is the current state of research and development in this area and how is the proposed program a transformative and disruptive approach relative to the current state?
- Why is now the right time to solve this problem?
- What research communities need to be brought together to create project teams to address the program goals?
- How does the program complement research and development efforts in other Department of Energy programs, other federal agencies, and the private sector?
- What happens at the conclusion of the program? How will the program transition? Who will be the early adopters? What are the barriers to commercialization and how might these problems be overcome?

Adapted from the DARPA Heilmeier questions

IV. POTENTIAL ENERGY TECHNOLOGY INVESTMENT AREAS

The inherent design of ARPA-E makes it impossible to predict in detail the specific technologies that will garner future investment. Nevertheless, ARPA-E envisions building from existing learning, often in a nonlinear and unexpected fashion, with a focus on both transportation and stationary energy, in the following broad areas:

Transportation Fuels: The incredible utility and energy storage capacity of chemical fuels ensure that they will remain in the nation's transportation infrastructure for years to come. The challenge lies in finding innovative ways to generate fuels from an ever increasing variety of feedstocks. Novel routes to create fuels from carbon-neutral feedstocks (biomass or carbon dioxide) offer the potential for transformative reductions in greenhouse gas emissions from the transportation sector. In the nearer term, the conversion of natural gas to liquid fuels, utilizing abundant domestic resources, offers both an enhancement in energy security and a significant step forward in reducing greenhouse gas emissions from vehicles. ARPA-E will continue to use advances in bio-engineering and biochemistry to develop photosynthetic and non-

photosynthetic routes to carbon-neutral fuels and to use chemical or biochemical approaches to find innovative ways to convert abundant domestic natural gas to transportation fuels.

Energy Materials and Processes: Much of advanced energy technology is centered on ways to convert energy from one form to another, using more efficient and cost effective methods. Advanced materials are central to the development of innovative energy conversion processes that improve efficiency in the generation and use of energy, with concomitant reduction in greenhouse gas emissions. ARPA-E has invested significantly in applied materials research in several programs and will continue to build upon new discoveries in fundamental material science to develop a broad range of materials for energy, including, but not limited to: catalysts, photovoltaics, structural materials, thermoelectrics, intelligent materials, semiconductors, magnetic materials, membranes, and others. Many of these new materials are well-tailored for specific function at the nanoscale level, but pathways for their cost-effective manufacture at the scale needed for energy technology do not yet exist. ARPA-E will continue to invest in research and development devoted to moving nanoscale materials from the realm of scientific discovery into real-world processes for improved energy utilization in engines, heating and air conditioning units, electric motors, power electronics, solar cells, wind turbines, data-intensive distributed computing, and many other technologies, some of which are only beginning to be envisioned for widespread applications to energy.

Energy Storage: A particularly important type of energy conversion is that in which energy is converted into a form that is readily stored for future use, such as when electricity is converted to chemical energy in a battery for later re-conversion back to electricity. More generally, the effective and inexpensive reversible conversion of electrical energy to a more easily stored form, such as chemical, mechanical, and thermal energy, remains a central challenge to the widespread adoption of electric vehicles and the increased penetration of intermittent renewable energy sources onto the electric grid. ARPA-E has made significant investments in electrical energy storage for both transportation and the grid. These programs have built new communities of scientists and engineers that are approaching the challenge of energy storage in new and exciting ways. Moreover, these projects exhibit an amplification of learning through crossovers between programs. Because of these new insights, ARPA-E continues to envision opportunities for new technology approaches to achieve efficient and inexpensive energy storage. For example, the storage of energy derived from the full solar spectrum and its ready conversion to electricity would be transformative in addressing the intermittency that currently limits the widespread penetration of solar electricity. In addition, ARPA-E has already seen successful energy storage advancements lead to further engagement in the energy marketplace. For example, a University-led battery project in a major city formed a new company and is progressing beyond its ARPA-E funding, and in another project, a small grid scale storage business is partnering and receiving

investments from several major corporations after a modest amount of research funding de-risked the advanced technology.

Sensors, Information, and Integration: As energy technology meets the information age, the need to collect, analyze, standardize, and protect energy information will grow and diversify over many energy systems. The transition to smart and resilient energy systems will be enabled by reliable and inexpensive sensors to provide essential data, analytical tools capable of dealing with the vast amounts of data created, and sophisticated control algorithms to optimize system performance. ARPA-E has invested in building the innovative new components that need to be integrated into larger systems to achieve full impact and now sees a broad opportunity in the combination of sensor technology, informatics, and system integration. ARPA-E currently invests in the development of advanced sensors and control technologies for battery management and control algorithms for the power grid. ARPA-E will explore the further development of hardware and software tools needed to characterize, optimize, and control additional smart, integrated energy systems of the future. Future investments in systems integration will not replicate scale-up and manufacturing issues that are best addressed by the Department of Energy applied technology programs or private industry.

V. CONCLUSION

Over the next three fiscal years, ARPA-E will continue to catalyze and accelerate the development of transformational energy technologies that could create a more secure and affordable American future. ARPA-E will maintain the use of its successful model to select projects through “focused” and “open” programs, quickly and effectively leveraging new scientific discoveries and market developments. ARPA-E will also continue to engage with academia, small and large businesses, other Department of Energy program offices, and other government agencies to facilitate relationships necessary for awardees to move to the next stage of their project development. In addition, ARPA-E will track and evaluate the success of awardee technologies after their participation in the program in order to more clearly demonstrate the transformative effects of ARPA-E’s investments.

VI. APPENDIX I: ARPA-E PROGRAMS

The table below lists ARPA-E programs as of March 2013:

Program Name	Year	Funding Available
OPEN 2009	2009	\$176 million
<p>ARPA-E's first funding opportunity, open to ideas from all energy areas and focused on funding projects with strong research and development plans for potentially high-impact technologies. ARPA-E received over 3700 concept papers and selected 36 projects.</p>		
OPEN 2012	2012	\$130 million
<p>ARPA-E's second open funding opportunity designed to catalyze transformational breakthroughs across the entire spectrum of energy technologies. ARPA-E received over 4,000 concept papers and selected 67 projects across 24 U.S. States, in 11 technology areas.</p>		
ADEPT - Agile Delivery of Electrical Power Technology	2010	\$38 million
<p>ADEPT is focused on dramatically improving the efficiency and cost of power conversion and switching, to improve efficiency across the electrical grid and in electrical applications from cars to computers.</p>		
AMPED - Advanced Management & Protection of Energy Storage Devices	2012	\$30 million
<p>The AMPED program is developing advanced sensing and control technologies to dramatically improve the performance and lifetime of grid-scale and transportation batteries.</p>		
BEEST - Batteries for Electrical Energy Storage in Transportation	2010	\$30 million
<p>BEEST seeks to develop a new generation of ultra-high energy density, low-cost battery technologies for long-range plug-in hybrid and all-electric vehicles.</p>		
BREETIT - Building Energy Efficiency through Innovative Thermodevices	2010	\$34 million
<p>BREETIT is developing new approaches and technologies for building cooling equipment and air conditioners to drastically improve building energy efficiency.</p>		
Electrofuels	2010	\$48 million
<p>The Electrofuels program is developing new ways to create liquid transportation fuels by using self-reliant microorganism that can directly use energy from electricity and chemical compounds, to produce fuel, bypassing photosynthesis.</p>		
GENI - Green Electricity Network Integration	2011	\$39 million
<p>The GENI program is modernizing the way electricity is transmitted in the U.S. through advances in hardware and software for the electric grid.</p>		

GRIDS - Grid-Scale Rampable Intermittent Dispatchable Storage	2011	\$39 million
GRIDS is developing storage technologies that can store renewable energy for use at any location on the grid at an investment cost less than \$100 per kilowatt hour.		
HEATS - High Energy Advanced Thermal Storage	2011	\$38 million
The HEATS program is developing revolutionary, cost-effective ways to store and use thermal energy.		
IMPACCT - Innovative Materials & Processes for Advanced Carbon Capture Technologies	2010	\$40 million
IMPACCT is focusing on technologies to minimize the cost of removing carbon dioxide (CO ₂) from coal-fired power plant exhaust by developing materials and processes.		
MOVE - Methane Opportunities for Vehicular Energy	2012	\$30 million
MOVE aims to engineer light-weight, affordable natural gas tanks for vehicles and develop natural gas compressors that can efficiently fuel a natural gas vehicle at home to provide cost-effective ways to power passenger cars and other light-duty vehicles with America's abundant natural gas resources.		
PETRO - Plants Engineered to Replace Oil	2011	\$37 million
PETRO is developing non-food crops that are designed to directly produce transportation fuels to create biofuels from domestic sources such as tobacco and pine trees.		
REACT - Rare Earth Alternatives in Critical Technologies	2011	\$28 million
The REACT program is identifying low-cost and abundant replacements for rare earth materials and advancing existing technologies to reduce or eliminate dependence on these materials.		
Solar ADEPT - Solar Agile Delivery of Electrical Power Technology	2011	\$14 million
The Solar ADEPT program is focusing on integrating advanced electrical components into PV systems to make the process of converting solar energy to electricity more efficient.		
SBIR/STTR	2012	\$13 million
ARPA-E's 2012 SBIR/STTR program is focusing on advancing transformational technologies that reduce barriers to mass adoption of electrical energy storage for stationary and transportation applications.		