Innovation for impact

https://arpa-e.energy.gov

As materials scientists, we all understand the benefits that R&D provides as a driver of improved quality of life and economic benefits. We also understand the long and difficult pathway from innovation to social benefit. The Advanced Research Projects Agency-Energy (ARPA-E) was established specifically to accelerate that process for the energy sector.

ARPA-E is a young agency, founded in 2007 as a result of the "Rising Above the Gathering Storm" report[1] (which emphasized that a comprehensive and coordinated effort is needed to bolster US competitiveness through support for research and development [R&D] in science and technology), and received its first funding in 2009. While the agency has only been in operation for a little more than seven years, it has big aspirations; its motto is "changing what's possible," and its assigned mission space spans the entire energy sector.

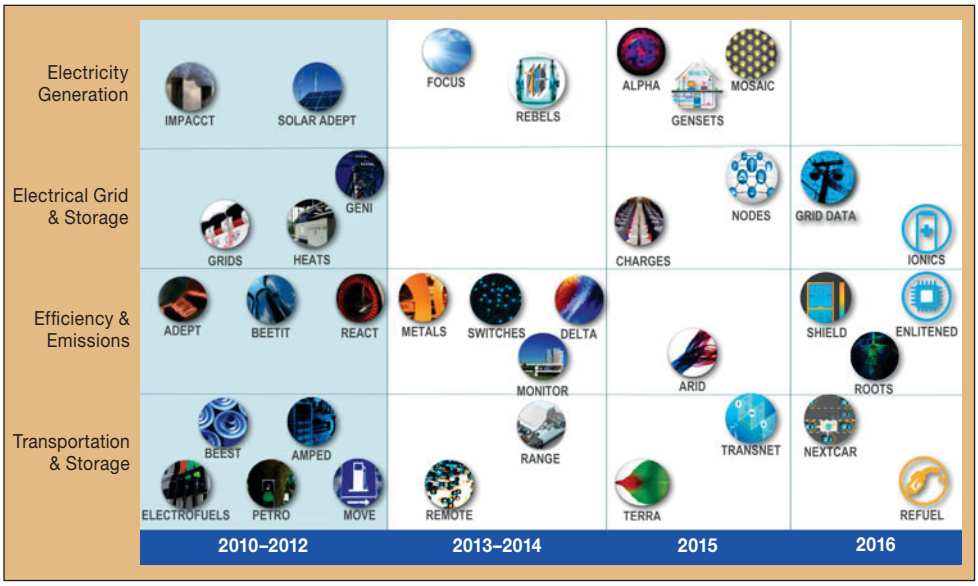
To put ARPA-E's mission in context, consider the evolution of US energy use over the past 150 years. In the 1850s, the United States was an agrarian society, generating virtually all of its energy by burning biomass, mostly wood. Shortly thereafter, the nation began to enter the Industrial Revolution, adding coal as an energy source. The early 1900s saw a rapid growth in the use of oil as a fuel with the advent of low-cost automobiles driving demand, followed by increasing use of natural gas for heat and power generation. In the last 50 years, there has been an uptake of non-fossil energy sources: nuclear power, hydropower, wind, solar, and continuing use of biomass now account for nearly 20% of US energy consumption. Equally striking is the change in the amount of energy used annually—nearly 50 times as much today as was used in 1850. Changes in the energy sector require decades of time because it is so large and so embedded in every aspect of the economy.

Today we face pressing needs to improve US energy and economic and environmental security, and to do so in the context of human-induced climate change. Fortunately, the nation can draw on the strong infrastructure of basic R&D outcomes and develop new technologies to enable the future energy system that we need. The goal of ARPA-E is moving from innovative results of basic R&D to social impact.

ARPA-E was established with three clear requirements. The first is to be an agent of change: to address innovation, to find new, possibly astounding advances in science and engineering, and to advance those toward applications in the energy sector. The second is to focus those benefits on energy efficiency, reducing energy emissions and reducing dependence on energy imports. The third is to promote US energy and economic security and to sustain US technological leadership in advanced energy technologies. As the agency plans its research programs, it focuses on these requirements with the mantra, "If it works, will it matter?"

The program structure that ARPA-E developed to meet its requirements is illustrated in the figure and shows all of the focused programs that ARPA-E has supported. Each of the circles represents a three-year, roughly USD$30 million research program (www.arpa-e.energy.gov/?q=program-listing) that includes about 10 project teams. Every year, about one-third of the programs end, graduating about one-third of the project teams, and ARPA-E starts new programs to develop new innovations. The vertical distribution shows the span of the energy sector covered by the programs: transportation and storage, efficiency and emissions, electrical grid and storage, and electricity generation. ARPA-E releases five or six focused opportunity (funding) announcements every year, and once every three years, an open solicitation for proposals on any topic within its energy mission. ARPA-E consistently receives many more high-potential proposals than it is able to fund.

All of these programs have been able to support profoundly creative and innovative project teams. ARPA-E's funding process is not grants; it is cooperative research



Map of ARPA-E-focused programs illustrates the breadth of coverage across the energy sector (vertical axis) and the turnover of programs (horizontal axis) to address new areas of innovation.

agreements in which the project teams work directly with ARPA-E program directors and commercialization advisors to advance their technology based on clear goals for the outcomes they want to achieve in the three years of ARPA-E support. This is a different approach to research, especially for university teams, and the agency is finding it very successful in moving innovative new ideas onto a pathway to commercialization.

Materials science is a critical enabler for about one-half of the projects in ARPA-E's portfolio of programs. In particular, improving wide-bandgap materials such as SiC and GaN has been essential to ARPA-E's power electronics programs. Materials also play a major role in ARPA-E's electrochemistry (batteries and fuel cells) programs, its resource efficiency programs, as well as for new approaches to solar power and building efficiency.

The ARPA-E approach draws on prior advances from basic, exploratory research programs, and the agency challenges its awardees to demonstrate the potential for those advances to enable new, high-performance energy technologies. In materials science, new opportunities abound due to the growing capabilities of materials discovery, computational materials design, nanostructured materials, and new growth and processing methods, including additive manufacturing. All of these are being exploited to create materials tailored for desirable properties and for commercially viable fabrication and use. Examples from ARPA-E's portfolio include a biomimetically designed low-friction coating,[2] cathode materials tailored to reduce stress–strain issues during battery charge cycles,[3,4] design of electrochemical membranes to lower reaction barriers and thus reduce over-potential,[5] and low-cost fabrication of semiconductor devices for solar power and power electronics.[6,7]

Success in ARPA-E projects encompasses coordinated factors—new opportunities stemming from early fundamental research, innovation, technical advances, and a focus on commercial pathways—which ARPA-E uses to gauge impact. Many examples can be found in the first two volumes of the agency's ongoing impact assessments.[8,9] In addition to in-depth technical assessments, ARPA-E also tracks key indicators of progress toward commercial uptake, working with each of the project teams. These statistics show that at the end of 2016, 56 ARPA-E teams started small companies as a result of their projects. Sixty-eight projects partnered with other government agencies for further development, and an ever-increasing number of technologies have been incorporated into products sold on the market today. Seventy-four project teams have attracted private sector follow-on funding, totaling more than USD$1.8 billion since the agency's founding in 2009. In coordination with these statistics, ARPA-E keeps track of its alumni teams as they field-test their technologies, produce beta products, and begin commercial deployment. Understanding the decadal time scale for changing the energy sector, ARPA-E collects data along project performers' success trajectories to gauge its role as a catalyzing agency.

The long-term goal of all of ARPA-E's programs is to create options for the energy sector that have real commercial potential. To accomplish this, the technologies its teams create must be at least economically competitive and preferably economically attractive. The results so far are very encouraging. The agency is approaching eight years of experience in applying a focused emphasis on moving those opportunities onto a pathway to impact, and has a portfolio of alumni projects that are increasingly demonstrating the success of this approach. It is expected that these innovation outcomes will continue to grow in impact on the time scales of the energy sector.

ARPA-E's success is stringently dependent on engagement with the technical community. Not only does the agency rely on the community for their proposals in response to its funding announcements, but it also constantly consults with the community as it develops new programs. The agency holds workshops to solicit expert input, releases requests for information, posts informational webinars, and turns to the community for support for reviewing proposals. ARPA-E also draws members of the community to work at the agency as program directors and commercialization advisors—all of its team members are hired through limited-term appointments. Some of them come on Intergovernmental Personnel Acts from universities or from national laboratories. Some of them come from industry or are former innovators. The agency looks for subject-matter experts across the energy sector. Its team members are empowered to evaluate needs and identify opportunities in innovation, and design new programs to suit.

Modernizing the energy system is an urgent need for our nation's security and prosperity. Technological advances can play a vital role in meeting this need, and materials science plays a critical role in such technical advances. Building on the US infrastructure of R&D and industrial know-how, ARPA-E takes on a cooperative approach to catalyze technologies for real-world market and energy impacts. The agency calls upon the materials science community to join its mission in changing what's possible.

Ellen D. Williams
Former Director of the DOE's Advanced Research Projects Agency-Energy
2016 MRS Fall Meeting
The Fred Kavli Distinguished Lectureship in Materials Science

References

1. The National Academies of Sciences, Engineering, and Medicine, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (National Academies Press, Washington, DC, 2007).
2. ARPA-E, *Slippery Coatings to Promote Energy Conversion* (US Department of Energy, Washington, DC, 2012).
3. ARPA-E, *Double Energy Density Anodes for Lithium-Ion Batteries* (US Department of Energy, Washington, DC, 2010).
4. ARPA-E, *Prussian Blue Dye Batteries* (US Department of Energy, Washington, DC, 2012).
5. ARPA-E, *Converting CO_2 into Fuel and Chemicals* (US Department of Energy, Washington, DC, 2012).
6. ARPA-E, *Cost-Effective Silicon Wafers for Solar Cells* (US Department of Energy, Washington, DC, 2009).
7. ARPA-E, *Advanced Manufacturing for SiC MOSFETS* (US Department of Energy, Washington, DC, 2013).
8. ARPA-E, *ARPA-E: The First Seven Years. A Sampling of Project Outcomes* (US Department of Energy, Washington, DC, 2016).
9. ARPA-E, *ARPA-E Impacts: A Sampling of Project Outcomes, Volume II* (US Department of Energy, Washington, DC, 2017).