U.S. Renewable Energy Policy: The Experience of Advanced Research Projects Agency-Energy

X M Qian
Middle East Studies Institute, Shanghai International Studies University, Shanghai, 200083, Shanghai, China
E-mail: qxmchris@126.com

Abstract. ARPA-E is playing an important role in developing revolutionary energy technologies that may impact US energy status. The role has become a powerful engine for new energy innovation in the United States. ARPA-E adopts a very flexible organization and management mode, and its operating mode has become a model for small organizations within the US government. In order to strengthen ARPA-E, the U.S. government has increased investment in recruiting talents, team culture, and technology research and development. The ARPA-E project in the United States has formed standardized procedures, systems and regulations in the management of new energy research projects, and can effectively and efficiently implement these contents, forming management characteristics and playing a high reference role for other countries' new energy research and development.

1. Overview of ARPA-E
ARPA-E (The Advanced Research Projects Agency-Energy) is playing an important role in developing revolutionary energy technologies that may impact US energy status. ARPA-E research program has become a powerful engine for new energy innovation in the United States. Since 2009, ARPA-E has provided approximately $1.8 billion in R&D funding for more than 800 potentially transformational energy technology projects. [1]

The main objectives of ARPA-E are: to reduce energy imports from abroad by developing advanced energy technologies, reduce emissions related to energy, thereby enhancing US economic and energy security. [2] By investing in and developing advanced technology for energy sources, it ensures the US' leading edge and makes clean energy technology less expensive than traditional technology. Investment in advanced energy research projects is very risky for the private sector, however, once successful, it will significantly increase the economic security and environmental security factors. The United States has an advanced R&D infrastructure and a vibrant, entrepreneurial and innovative ecosystem. It is in this American spirit that ARPA-E discovers and supports pioneers who guide the United States toward the future. ARPA-E achieves its goals with new energy research projects through the following efforts: (1) discovering and promoting the progress of revolutionary research in basic and applied sciences; (2) transforming scientific discoveries into applicable technology and turning cutting-edge inventions into technological innovation; (3) Due to the uncertainty of technology and capital, some convertible technologies themselves cannot accelerate development, while ARPA-E accelerates the development of these technologies.

ARPA-E only invests in and focuses on revolutionary energy technologies that have the potential to make a significant impact on the US energy landscape. “Revolutionary” technology refers to...
technologies that can completely change the status quo. The project investment plan often has great uncertainty in terms of technology and finance, that is, there are inherent risks and not all of them can end up with being successful. But once these projects successfully enter the market, they will create new industries and job opportunities, develop more economical energy technologies, and accelerate the realization of US energy goals. ARPA-E projects have helped advance scientific understanding and technological innovation through 2,489 peer-reviewed journal articles and 245 patents issued by the U.S. Patent and Trademark Office.\[1\]

As shown in table 1, ARPA-E did not have a budget after its establishment until 2009, when it obtained its first $403.8 million budget through the US Recovery Act. By January 2012, ARPA-E had a total federal budget of $843.5 million, providing $521.7 million in funding for 180 projects. The budget for fiscal year 2011 and fiscal year 2012 had shrunk, and ARPA-E had withstood this test to gain bipartisan support, and Congress would continue to support the project.

| Fiscal Year | Amount | Funding Source |
|-------------|--------|----------------|
| 2009        | 388,856| The U.S. Recovery Act(388.8); and the rest from Congressional appropriation (15) |
| 2010        | 0\(^b\) | Congressional appropriation |
| 2011        | 179,640| Congressional appropriation |
| 2012        | 275,000| Congressional appropriation |
| 2013        | 250,636| Congressional appropriation |
| 2014        | 280,000| Congressional appropriation |
| 2015        | 279,982| Congressional appropriation |
| 2016        | 291,000| Congressional appropriation |
| 2017        | 305,245| Congressional appropriation |
| 2018        | 353,314| Congressional appropriation |
| 2019        | 366,000| Congressional appropriation |

\(^a\) https://www.arpa-e.energy.gov/?q=arpa-e-site-page/arpa-e-budget.
\(^b\) The United States House of Representatives Report H. Rpt. 111-203 provides explanation for why the FY 2010 appropriations bill (Public Law 111-85) did not fund ARPA-E. It stated that the FY 2009 congressional appropriations and the Recovery Act funding would allow ARPA-E fund its first round of awards in FY 2010, and noted, “The decision not to provide any additional funding for ARPA-E in fiscal year 2010 beyond funding already provided does not in any way suggest a lack of commitment to this new program by Committee.” Stine, Deborah D., America COMPETES Act and the FY2010 Budget (Washington, DC: Congressional Research Service, 2010), http://www.fas.org/sgp/crs/misc/R40519.pdf.

Some of the projects supported by ARPA-E have achieved technical and commercial success, and have received a large number of additional investments and even established related start-ups.

The goal of ARPA-E is to help the early development of revolutionary energy. Table 2 is a widely used measure of Technology Readiness Levels (TRL). [3][4] As shown in table 2, the projects ARPA-E funded are mostly between the stage of technical concept (TRL2) to experimentation and verification (TRL4). The interval between TRL2 and TRL4 is called the “Death Valley” of technology development, and the investment risk of development projects at this stage is very high. ARPA-E is to fund the revolutionary energy research program in the early stages.

\[\text{Table 2.} \text{ The annual funding source of ARPA-E (in thousands of US dollars)\textsuperscript{a}}}\]

\[\text{Fiscal Year} \quad \text{Amount} \quad \text{Funding Source} \]
\[2009 \quad 388,856 \quad \text{The U.S. Recovery Act(388.8); and the rest from Congressional appropriation (15)} \]
\[2010 \quad 0\textsuperscript{b} \quad \text{Congressional appropriation} \]
\[2011 \quad 179,640 \quad \text{Congressional appropriation} \]
\[2012 \quad 275,000 \quad \text{Congressional appropriation} \]
\[2013 \quad 250,636 \quad \text{Congressional appropriation} \]
\[2014 \quad 280,000 \quad \text{Congressional appropriation} \]
\[2015 \quad 279,982 \quad \text{Congressional appropriation} \]
\[2016 \quad 291,000 \quad \text{Congressional appropriation} \]
\[2017 \quad 305,245 \quad \text{Congressional appropriation} \]
\[2018 \quad 353,314 \quad \text{Congressional appropriation} \]
\[2019 \quad 366,000 \quad \text{Congressional appropriation} \]
Table 2. Measures of Technology Readiness Levels*

| Technology Readiness Levels | Technical progress                                                                 |
|-----------------------------|-------------------------------------------------------------------------------------|
| TRL1                        | Find problems and propose theoretical analysis                                       |
| TRL2                        | Technical concept                                                                    |
| TRL3                        | Proof of concept through theoretical and experimental analysis                       |
| TRL4                        | Completed sample verification in a lab environment                                    |
| TRL5                        | Completed sample verification in an approximate environment                           |
| TRL6                        | Completed the demonstration of the (sub)system model in the approximate environment   |
| TRL7                        | Completed the demonstration of the system model in the operating environment           |
| TRL8                        | Formed a complete practical system through testing and demonstration and gained the qualification |
| TRL9                        | The actual system is verified by a successful run                                      |

*Thuy Mai, 2012 Technology Readiness Levels, (Washington, D.C, USA: Advanced Concepts Office, Office of Space Access and Technology, NASA.) p 1.

ARPA-E takes a number of steps to ensure the business value of the investment plan, such as considering market impact when developing a new plan; establishing a unique organizational structure that can carefully manage risk and provide funding, technical and commercial support for different types of projects; actively management over the projects it invests in; conducting a monitoring record of the technology development process every quarter, and frequently visiting the project development site; and if necessary, quickly deciding to suspend the project. ARPA-E project teams have continued to advance their technologies: 76 new companies have formed, 131 have partnered with another government agency, and 145 teams have raised more than $2.9 billion in private-sector follow-on to advance their technology toward the market. [1]

2. The organization management mode of ARPA-E

ARPA-E adopts a very flexible organization and management mode, and its operating mode has become a model for small organizations within the US government. ARPA-E recruits a number of top talents from the scientific, engineering and commercial fields. They act as the program managers of the plans for a certain period, and are responsible for the management of the project. The supervisors of the program manager report directly to the Energy Minister. A flat organizational structure enables projects to operate efficiently. The program manager is also an active participant in the project, working with the project undertaker to resolve technical issues and ensure that the project moves in the desired direction. When the project fails to meet technical milestone requirements, the program manager will consider performance improvement measures and may eventually recommend termination of the project and transfer funds to more promising projects. The Director and the Deputy Director are responsible for managing these project managers and will regularly review the progress of
the program. Through these measures, ARPA-E is able to assume regulatory responsibility for the funds that taxpayers pay. [5]

2.1 The program management and team culture
In order to strengthen ARPA-E, the U.S. government has increased investment in recruiting talents and team culture.

So far, ARPA-E has established an ongoing network of experts for the recruitment of employees. Many employees are top experts in their respective fields; many have business experience in large corporations, research laboratories and universities.

However, since ARPA-E employees are temporary employees for 3-4 years, they have to constantly recruit new people. The main attraction is that ARPA-E is the most cutting-edge, most exciting and challenging technical task in the entire energy sector. The compressed budget environment can make it difficult for newcomers to join, so new employees can't confirm whether they have enough resources to solve the problem completely or choose the project they think is the most promising. The original goal suggested by the National Academy of Sciences was originally set at an annual budget of $1 billion. The $100 million budget proposed by the House of Representatives will make ARPA-E less than one-third of the average venture capital fund, a small investment compared to the revenue of energy industry. It is certainly helpful, but not enough, to increase the fund to $180 million at the last minute of the House of Representatives. Persuading rapidly-changing venture capitalists with tenures in labs to leave their current positions for three years of challenging energy work, the difficulty of which has become bigger due to poor resource and great uncertainty.

One factor in the success of ARPA-E is that project managers communicate and share knowledge among researchers in various fields and institutions. Project managers organize seminars to attract top experts to discuss the most important energy issues to support. At the seminar, the project managers proposed a project to solve a specific technical problem, and then a further round of debate on the proposal among the project managers. After feedback, they are refined to the final approval; ARPA-E applied for funding for each of the proposed projects. After that, those recommendations are subject to a detailed review process by peers, including external opinions from leading technicians, engineers, and scientists in the field. The key feature of this process is that peer review is not a closed door. Instead, the applicant reads the review comments and provides a counter-evidence, which is taken into account when the project manager selects funds.

2.2 Breakthrough in technology
Even with the limited initial funding resources, ARPA-E's talent and teamwork have continued to improve the technology.

ARPA-E's "Power Technology Agile Transmission" program aims to create the 21st century power electronics that make equipment smaller, cheaper, smarter and more energy efficient, which will help end users use power equipment such as switches, transistors, and substation platforms.

Batteries are very important element that cause electric cars are more expensive but perform worse than fuel cars. If you don't have a battery that's cheap enough to charge at every 500 miles at a time, electric cars may never as popular as fuel cars. Recently, a start-up funded by ARPA-E, 24M Technology, received a $10 million fund for its innovative flow battery, which can be injected into an energy storage sticker.

Carbon capture and storage (CCS) is a transitional technology that is ultimately close to zero carbon emissions. If the technology could reduce the cost to a certain level, there will be no harmful carbon emissions with the assistance of the CCS technology, which allows continues use of coal-fired power plants. To date, the Innovative Materials and Process of Carbon Capture Technology (IMPACCT) program has advanced the development of innovative methods of carbon capture.

3. ARPA-E project and its approval
The R&D process of ARPA-E can be represented by a technology R&D model. As shown in figure 1, the whole life cycle is a process of technology application, discussion, evaluation, project implementation and technology market application.

![Figure 1. The whole life cycle](image)

ARPA-E has a rigorous evaluation and advancement process for energy technology innovation. ARPA-E contains many demand projects that fund a particular energy source. The ARPA-E project begins with the idea of a technology, and after that, it communicates the energy technology solutions with scientific, technical, and commercial experts through technical seminars, to explore the need for an energy source. Technical seminars focus on getting through basic and applied sciences, connecting science and technology with markets. If the results of the technical seminars meet the requirements for the establishment of the project, ARPA-E plans to set up a new project, which will be released and the project funding notice will be posted on the DOE website for project proposals. [6]

The projects generally last 6 to 8 months from the start of the program to the conclusion, with a minimum life of 2 months. As shown in figure 2, the process is: plan start (creatives, visions) - technology "deep dive" - internal discussion - in-depth revision and preparation of fund-assisted announcements - release of project funding announcements - plan review - panel review proposal - project selection - grant amount announcement - Contract negotiation and funding.

![Figure 2. ARPA-E’s Program Development Process](image)

The new plan needs to compare more than 10 criteria to verify the necessity to establish the plan. These guidelines cover the state of science, technology, and market in the field; the technical
challenges that exist; the risks, time, and non-technical barriers for technology to translate into productivity.

Applicants of funding projects include business entities, educational institutions, non-profit corporations, and various US government entities. When deciding which specific project to fund, ARPA-E will make a decision based on the opinions of external energy experts. Applicants are allowed to answer or refute these comments before the funding decision of ARPA-E. [6] The funded projects of ARPA-E are of the characteristics: (1) High impact: the projects can enhance US energy security and ensure that the United States is leading the way in research and use of advanced energy technologies. It has a major impact on the economic development and social progress of the United States. (2) Technical breakthrough: The breakthrough energy technology identified by ARPA-E can break through the current technical bottleneck. (3) High added value: The research field and selected projects of the ARPA-E program are both advance to other research at home and abroad in the early stage of technology research and development. (4) First-rate team: ARPA-E accelerates energy technology innovation by teaming up scientists and engineers; it brings together top talents to foster project development.

ARPA-E advocates the integration of open discussions in all areas of science, technology and business. Before the ARPA-E investment plan was decided, the project manager listened to the experts to evaluate the current new technologies and their development opportunities, which can break the barriers between various industries, and eliminate the gap between theory and practice. It also contributes to finding out the difficulties and breakthroughs in the connection between scientific theory and technology, and the market. The selected project must meet the two conditions of “technical thrust” and “market drive”. For instance, the applications are evaluated based on Impact of the Proposed Technology (30%), Overall Scientific and Technical Merit (30%), Qualifications, Experience, and Capabilities of the Proposed Project Team (30%), Soundness of Management Plan (10%). Include the following criteria: Whether the proposed work is unique and innovative; Clearly defined project outcomes and final deliverables; Substantiation that the proposed project is likely to meet or exceed the technical performance targets identified in this FOA; Feasibility of the proposed work based upon preliminary data or other background information and sound scientific and engineering practices and principles; A sound technical approach, including appropriately defined technical tasks, to accomplish the proposed R&D objectives; and Management of risk, to include identifying major technical R&D risks and feasible, effective mitigation strategies. [7]

4. Conclusion
The ARPA-E project in the United States has formed standardized procedures, systems and regulations in the management of new energy research projects, and can effectively and efficiently implement these contents, forming management characteristics and playing a high reference role for other countries’ new energy research and development.

First of all, the scientific and rigorous project evaluation mechanism guarantees the objectivity and impartiality of establishment, process management and acceptance activities of the projects, and ensures the effective realization of the objectives of the plan. The selection of review experts has strict standards. Most of the comments were based on anonymity, and the evaluation criteria and procedures were published to the public. The review process was highly transparent. In particular, a project's review team is often attended by multiple parties. There is no affiliation between the parties, and they are relatively independent. This makes it possible to monitor each other and ensure the accuracy of the results.

Second, the project process management implements a full life cycle management model. There are not only project review and completion acceptance, but also phased, node or milestone mid-term inspection and review in accordance with the specific characteristics and requirements of the project during the project process, tracking and control from the aspects of quality, progress, financial expenditure, etc., to ensure that decomposed goal under the general target is achieved, and the risk is reduced as much as possible. The government can control the investment of the research project in
stages, and decide whether to continue investing in the project according to the evaluation of the project implementation. The results of the mid-term inspection will directly affect the disbursement of funds for the next year. [8]

Third, the US government funded new energy research projects as a competitive model for directional projects. Since the budget of government research institutions is mostly derived from the budget allocation of federal government, the State's allocation to scientific research institutions is oriented, and the State adjusts the funding quotas of each institution according to the annual fiscal revenue and expenditure status, national needs and institutional performance. The laboratories and research groups within the organization compete for research funding in the form of projects. Through the internal competition of funds, it will achieve the survival of the fittest programs, to ensure the high quality of government-funded research activities. [9]

Fourth, a flexible organizational management model. The ARPA-E project operates efficiently; it lasts about 6 to 8 months from establishment to implementation, and the project implementation period is generally 1 year and a half to 3 years. ARPA-E has a flat organizational structure, through the appointment of top talents in science, engineering and business as project managers with limited term, it maintains their terms of office consistent with the project implementation cycle; the program manager is responsible for both the project and to the Director of ARPA-E. This speeds up the planning process and the selection process of the project, and also ensures that the goals and mission are achieved under strict time constraints.

Acknowledgements
This research was financially supported by Shanghai Pujiang Program.

References
[1] Ann X Y Z 2018 ARPA-E Impacts: A Sampling of Project Outcomes 3 p X1
[2] John F, Sargent Jr 2010 America COMPETES Act and the FY2010 Budget (Washington, DC: Congressional Research Service) p X1
[3] Thuy M 2012 Technology Readiness Levels (Washington, D C, USA: Advanced Concepts Office, Office of Space Access and Technology, NASA) p 1
[4] Nate D T, Elizabeth M, Anthony T 2017 Technology Readiness Levels Guidebook (Cambridge, USA: U.S. Department of Transportation Volpe Center) pp 1-9
[5] Zhu X J 2012 U.S. Advanced Research Projects Agency-Energy and its Project Planning China Electric Power 45 p 74
[6] Fred U, Jeff B et al 2010 ARPA-E, FY2010 Annual Report (Washington, DC: ARPA-E) p 3-4
[7] ARPA-E 2018 Financial assistance funding opportunity announcement, ARPA-E, No. DE-FOA-0001953, p33-34
[8] Li J 2005 Comparative Analysis of Project Management Models of Science and Technology Projects at Home and Abroad Coal Economic Research 8 p15
[9] Wu J G 2009 Study on the Management Model of Funds Allocation in National Research Institutions in the United States The Impact of Science on Society 1 p27