# INNOVATION IN THE US ENERGY SECTOR AS SEEN THROUGH ARPA-E

## — PUBLIC–PRIVATE COLLABORATION FOR HIGH-RISK, HIGH-IMPACT OUTCOMES —

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## SUMMARY

- ARPA-E promotes technological innovation in the energy sector through programs under the DOE. A close examination of ARPA-E's involvement in technology development provides an understanding of the innovations that are being pursued with the goal of practical application. This knowledge also helps capture opportunities for the creation of new businesses in the energy sector.
- Delving into the technology areas addressed by ARPA-E and the DOE's targeted focus areas, as well as exploring ongoing projects within the programs, can offer valuable insights for developing effective business proposals.
- The author attended ARPA-E's annual briefing to gather information on programs for long-term electric power storage and ocean $CO_2$ removal. These sessions provided details including the development goals, approaches, and the key companies and research institutions involved.

## 1. ABOUT ARPA-E AND THE INFORMATION IT CAN PROVIDE

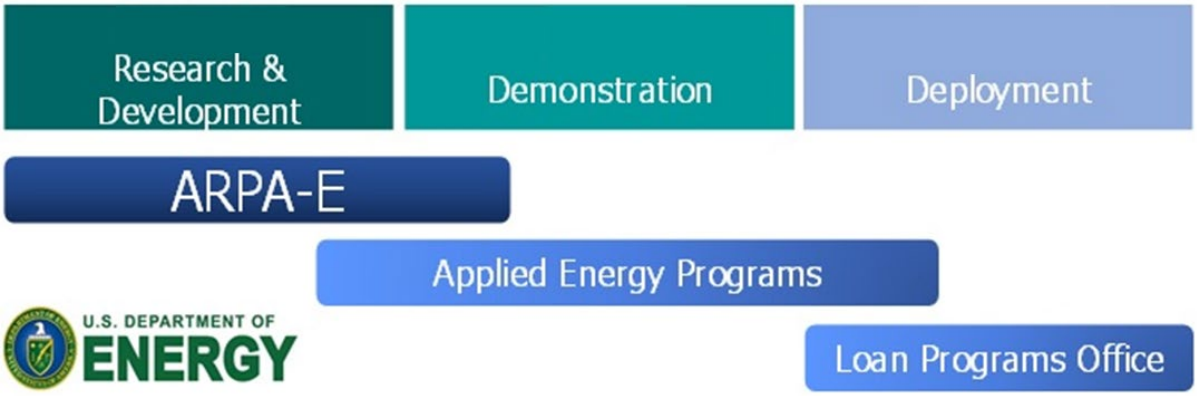
### 1-1. Innovations pursued under ARPA-E

ARPA-E stands for Advanced Research Projects Agency-Energy, a research and development agency established in 2007 by the US Department of Energy (DOE) to improve energy and economic security.[1] Learning from past successes of the Defense Advanced Research Projects Agency (DARPA), which developed the Internet and GPS, the DOE seeks high-risk, high-impact innovations in the energy sector through ARPA-E.

Development phases targeted by ARPA-E include the stages from basic research and development (R&D) through to initial demonstration (see Figure 1). When attempting to progress from basic R&D in the laboratory to prototype-based demonstration, developers encounter various technical challenges in areas such as scale-up reproducibility. ARPA-E was designed to provide support to help these developers overcome the technical challenges of the so-called "valley of death" stage, as well as the difficulty of securing funding. For full-scale demonstration and deployment efforts, the Applied Energy Programs and the Loan Programs Office[2] provide support to facilitate steady progress toward commercialization for promising innovations.

[1] DOE ARPA-E, https://arpa-e.energy.gov (accessed May 29, 2023)
[2] The Applied Energy Programs and the Loan Programs Office are programs and an organization established within the DOE to provide support for commercialization from the demonstration stages through to the mass production framework setup phase.

**Figure 1: R&D stages covered by ARPA-E**




出所： Compiled by MGSSI based on "Energy Innovation in the FY 2021 Budget: Congress Should Lead," INFORMATION TECHNOLOGY & INNOVATION FOUNDATION
https://www2.itif.org/2020-energy-innovation-funding-full-report.pdf (accessed May 29, 2023)

As of April 2023, there are 45 separate ARPA-E programs under which more than 1,400 projects are underway, with each project receiving an average of two to three million US dollars in development funding. In addition to financial support, DOE specialists provide technical and business expertise and strategic guidance to accelerate the transition from R&D to demonstration and commercialization.

An outline of major accomplishments under this framework is shown on the ARPA-E website, including impacts of innovation and technology demonstration results for 81 projects (see "ARPA-E Impacts: A Sample of Project Outcomes," volumes I through III[3]). For example, ARPA-E's Robust Affordable Next Generation Energy Storage Systems (RANGE) program[4], led by the University of Maryland, includes a project to develop high-durability, low-cost all-solid-state batteries for use in electric vehicles. Technological innovations in these batteries reduce heat generation compared to conventional batteries, improving safety and eliminating the need for expensive cooling equipment. Ion Storage Systems, a startup spun out of the University of Maryland, is in charge of demonstration and commercialization, currently preparing for mass-production market release.

## 1-2. Reasons for examining ARPA-E and the benefits of learning about its programs

As we see with the RANGE program's next-generation battery concept, a general look at ARPA-E programs allows us to learn more about the areas and technologies on which organizations such as DOE, universities, corporations, and research institutions are focusing their energies. In this way, ARPA-E can serve as an effective source of information in the quest to create new energy businesses based on innovation.

ARPA-E programs are organized around three categories: electricity generation and delivery, efficiency, and transportation; Figure 2 shows the programs within each category. In the electricity generation and delivery category, the primary focus since 2020 has been new types of nuclear reactors and nuclear fusion, as the number of such programs has been increasing. In efficiency, programs have varied widely, although two of them have focused on energy-usage reductions in data centers. Programs in this category address energy-related issues in ICT that are expected to increase in the future. Finally, in transportation, much of the focus has been on creating automobiles and airplanes that do not depend on fossil fuels, with particular emphasis on storage batteries, airplane electrification, and biomass fuel development.

Although these programs vary greatly in their contents, they are organized by sector, category, and technology under ARPA-E, making it relatively easy to understand which technologies of note are involved in each. In

[3] "Press Kit," DOE ARPA-E, https://arpa-e.energy.gov/news-and-media/press-kit (accessed May 29, 2023)
[4] ARPA-E Energy Innovation Summit, https://www.arpae-summit.com/Home (accessed May 29, 2023)

addition, a closer look at each program's projects provides information on the goals, challenges, and progress of each company and research institution involved in the technology development effort. This information can be used as a reference for technical evaluations.

**Figure 2 ARPA-E Technology Categories and Programs**

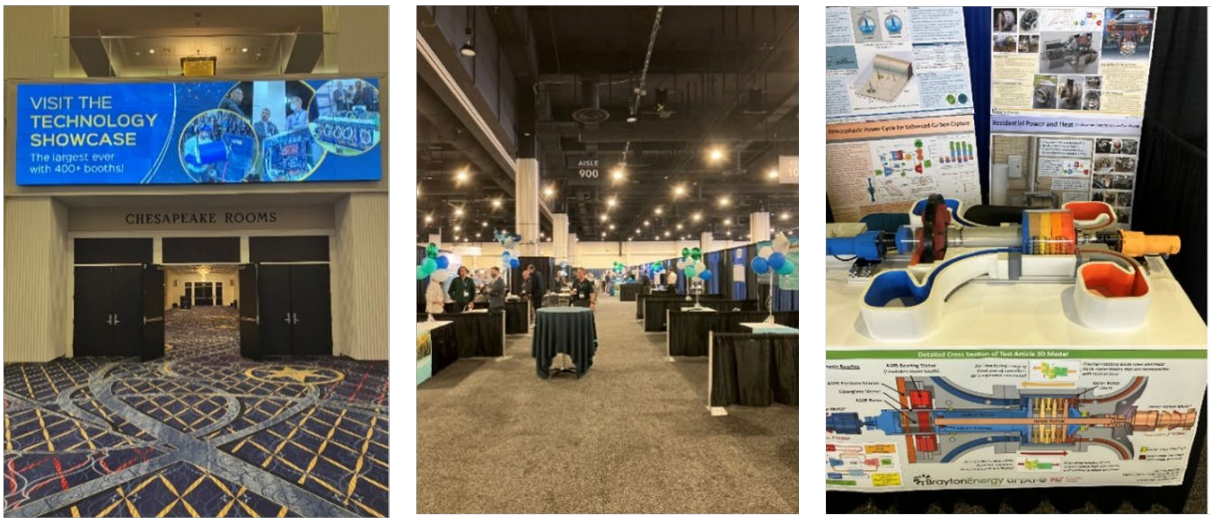
| Technical Categories | | Programs（Start year） |
|---|---|---|
| Electricity Generation & Delivery | Distributed Energy Resources<br>Generation<br>Grid<br>Storage | GENSETS: Residential CHP systems（2015）<br>NODES: Network optimized distributed energy（2015）<br>GRID DATA: Power system network models（2016）<br>IONICS: Novel Ion-conducting solids（2016）<br>INTEGRATE: Natural gas distributed generation（2017）<br>MEITNER: Advanced nuclear reactors design（2018）<br>BREAKERS: Direct current circuit breakers（2018）<br>DAYS:Long duration energy storage systems（2018）<br>GO Competition: Grid Optimization Competition（2018）<br>ATLANTIS: Floating offshore wind turbine（2019）<br>GEMINA: Digital twin for advanced nuclear reactors（2019）<br>BETHE: Thermonuclear-fusion energy（2020）<br>GAMOW: Fusion plasma & plant design（2020）<br>PERFORM: Grid management systems（2020）<br>SHARKS: Hydrokinetic Turbines for tidal and river（2020）<br>ONWARDS: Advanced Reactor Disposal Systems（2021）<br>CURIE: Recycling used nuclear fuel（2022）<br>GOPHURRS: Grid overhaul（2023）<br>ULTRAFAST: Faster power semiconductor（2023） |
| Efficiency | Building Efficiency<br>Electrical Efficiency<br>Manufacturing Efficiency<br>Resource Efficiency | ROOTS: Carbon sequestration by plant substrates（2016）<br>SHIELD: Building insulation（2016）<br>CIRCUITS: Advanced power electronics（2017）<br>ENLITENED: Datacenter energy efficiency（2017）<br>PNDIODES: Power electronics devices（2017）<br>SENSOR: Sensors for building（2017）<br>HITEMMP: High intensity thermal exchange（2018）<br>DIFFERENTIATE: AI, machine learning（2019）<br>FLECCS: Carbon capture and storage（2020）<br>REPAIR: Natural gas pipeline maintenance（2020）<br>ULTIMATE: Materials for gas turbines（2020）<br>Exploratory Topics: Energy tech. innovation（2020）<br>ECOSynBio: Biomass conversion platforms（2021）<br>HESTIA: Low carbon building design（2021）<br>REMEDY: Reducing emissions of methane（2021）<br>COOLERCHIPS: Cooling tech. for data centers（2022）<br>MINER: Mining innovations for negative emissions（2022）<br>SEA CO2: Marine carbon dioxide removal (mCDR)（2023） |
| Transportation | Transportation Energy Conversion<br>Transportation Storage<br>Transportation Fuels<br>Transportation Network<br>Transportation Vehicles | RANGE: Batteries for EV（2013）<br>REFUEL: Carbon-neutral liquid fuels (CNLFs)（2016）<br>NEXTCAR: Connected and automated vehicle（2016）<br>MARINER: Macroalgae marine biomass energy（2017）<br>ASCEND: All-electric powertrain for aircraft（2019）<br>REEACH: Fuel cell for aircraft（2019）<br>SMART FARM: Biofuel supply chain monitoring（2020）<br>EVs4ALL: EV next-generation battery（2022） |

Source: Compiled by MGSSI based on ARPA-E website

## 2. PROMINENT PROGRAMS AT ARPA-E ENERGY INNOVATION SUMMIT 2023

In addition to presenting information about programs and their results on the website, ARPA-E reports on them at the annual ARPA-E Energy Innovation Summits.[5] The exhibition, known as the "Technology Showcase," provides highly useful information, including in-depth technical explanations by developers and face-to-face interviews with them about development status and progress.

**Figure 3: ARPA-E Energy Innovation Summit**




Source: Photo by the author

Some examples of useful information sources from Summit 2023 include the projects related to long-term electric power storage and ocean $CO_2$ removal, which are considered to have a high impact from a decarbonization perspective.

**Long-term Electric Power Storage: The DAYS (Duration Addition to electricitY Storage) Program**

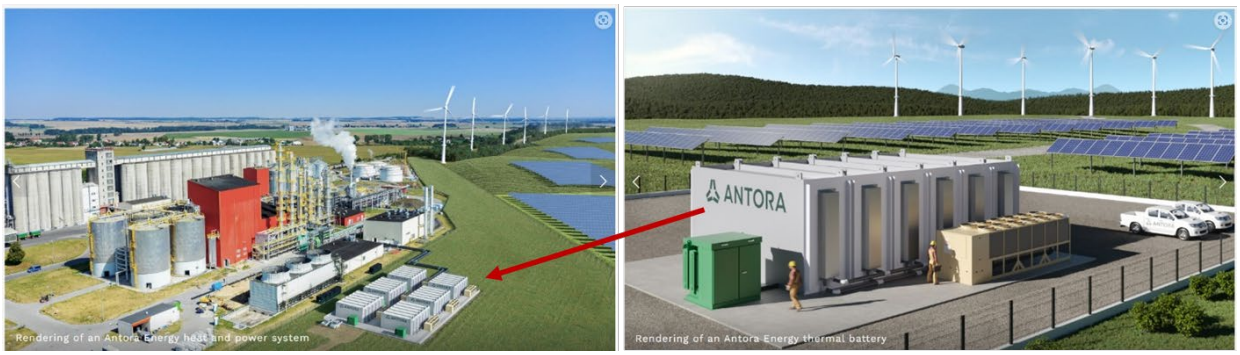
Renewable energy can only generate electricity when the sun is shining or the wind is blowing, and cannot adjust its production to match demand as thermal power generation can. Therefore, energy storage is needed to correct this imbalance. Storage batteries, such as lithium-ion batteries, are only designed for short-term storage lasting about four to five hours. In response, many developers are working to achieve technologies that enable longer-term energy storage.

Antora Energy is currently developing an energy storage system that stores thermal energy in inexpensive carbon (graphite) blocks. This approach uses electrical resistance heating to convert electricity into heat, accumulating the heat in the blocks, raising the temperature to 2,000 degrees Celsius, and storing the resulting thermal energy. Later, thermophotovoltaic (TPV) panels are exposed to the heat stored in these high-temperature blocks to generate electricity. With TPV panels, storing energy is straightforward and enables long-term retention. Unlike turbines, TPV panels do not require a rotating device , thus improving power generation efficiency, and the use of low-cost graphite material brings down overall equipment costs. A 3-megawatt system is currently undergoing demonstration in California. Antora Energy plans to launch a pilot test program at four to six locations with an eye toward future commercial applications.

[5] Replaces the negative electrode of a lithium-ion battery with lithium metal and liquid electrolyte in the separator, and uses a solid ion conductor for the positive electrode

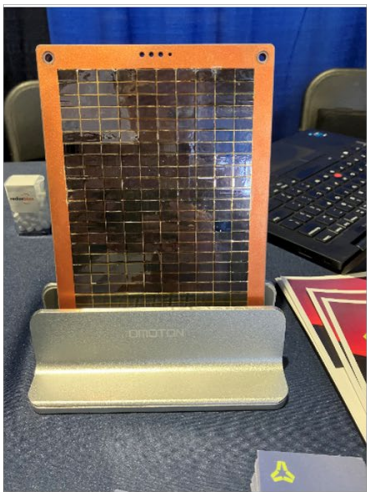
**Figure 4: Antora Energy's thermal energy storage system**

Thermal energy storage system adjacent to a chemical plant to supply heat and electricity




Carbon block

Thermal photovoltaic panel



Source: (Photo above) ACTIVATE GLOBAL website
https://www.activate.org/news/antora-energy-storage-industry-breakthrough-lowercarbon
(accessed May 29, 2023)
(Photo below) Photo by the author

**Direct Ocean Capture: Exploratory Topics Program**

Direct Air Capture (DAC) is a means of directly capturing $CO_2$ from the air in pursuit of net-zero $CO_2$ emissions. Similarly, Direct Ocean Capture (DOC) is an increasingly promising means of capturing $CO_2$ directly from the ocean, and ARPA-E is involved in DOC technology development.

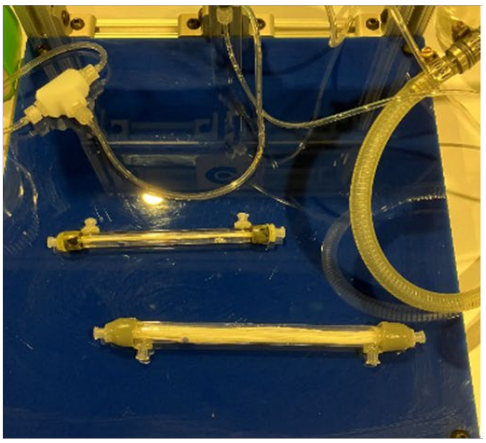
Captura Corporation is developing thin-film composite hollow-fiber membranes to efficiently recover $CO_2$ from seawater. By improving upon existing low-cost hollow-fiber membranes commonly used for water filtration, the company has made possible the selective separation of $CO_2$ from seawater. Captura's development goal is to realize $CO_2$ capture with energy and cost that are between half and one-fourth of those required for DAC. The company is currently conducting a pilot test program in the Gulf of California on a scale of 100 tons of $CO_2$ annually.

In March 2023, the US announced its Ocean Climate Action Plan,[6] demonstrating the high priority placed by the nation on climate change measures for oceans and seas. Ocean $CO_2$ removal is highlighted as a priority area in the plan, and the action plan includes the promotion of R&D, environmental impact assessment, and development of regulatory standards. In terms of commercialization, the sale and purchase of carbon credits based on captured marine $CO_2$ is a source of profit for this business. Various companies, including Microsoft Corporation and Stripe, Inc., a financial service provider, have already made pre-purchases of carbon credits. Furthermore, start-up financing and various efforts to establish businesses in this area are accelerating.

**Figure 5: Captura's Direct Ocean Capture**

Image of equipment to be installed at sea

Hollow-fiber membrane



Source: (Left) Captura website, https://twitter.com/CapturaCO2 (accessed May 29, 2023)
(Right) Photo by the author

## 3. CONCLUSION

ARPA-E pursues high-risk, high-impact innovations. It is an ideal resource when looking for technologies that, if successful, have the potential for large markets and high profits. ARPA-E Energy Innovation Summits provide excellent opportunities for face-to-face discussions with developers, as well as networking for future industry collaboration and funding. Although one's organization must be a corporation or research institution located within the US to be selected for participation in ARPA-E programs, a Japanese company is eligible if it has an affiliate in the US. Moreover, Japanese companies can take a more indirect route to program participation by engaging in joint technology development with a participating organization. In other words, ARPA-E can be more than just a source of useful information.

Since 2021, the US has enacted the Bipartisan Infrastructure Act and the Inflation Reduction Act, and has begun to invest heavily in decarbonizing infrastructure improvements and technological innovation while accelerating its energy transition. In order to monitor whether US policies are making concrete and practical progress, it would be beneficial to pay close attention to the ARPA-E programs.

[6] The Ocean Climate Action Plan establishes climate change measures for a wide range of sectors and industries relating to (1) decarbonization of oceans and seas, encompassing ocean energy, ocean $CO_2$ removal, and $CO_2$ seabed storage; (2) seabed resources; (3) marine resources (fishing & aquaculture); and (4) marine transport, dock and harbor facilities, shipbuilding, and the like.