U.S. DEPARTMENT OF ENERGY

# Advanced Research Projects Agency–Energy Annual Report for FY 2016

**Report to Congress**
**September 2017**

**United States Department of Energy**
**Washington, DC 20585**

# Message from the Acting Director

The Advanced Research Projects Agency-Energy (ARPA-E) maintains a dynamic funding portfolio in which roughly one third of programs turn over annually. ARPA-E supports project teams whose technologies advance the boundaries of science and provides them with the strategic guidance necessary to effectively prepare for the deployment of their technologies.

In Fiscal Year 2016, we continued developing our diverse portfolio of advanced energy technologies. We issued seven Funding Opportunity Announcements (FOAs) including one to utilize on-board or cloud-based sensors, data and computational capabilities to make cars and trucks more energy efficient (NEXTCAR) and another to double datacenter efficiency as our economy becomes increasingly digitized (ENLITENED). Moreover, we announced projects ranging from developing realistic, open-access models and data repositories to aid in improving the U.S. electric grid (GRID DATA) to paving the way for technologies that overcome the limitations of current battery and fuel cell products (IONICS).

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

- **The Honorable Lisa Murkowski**
  Chairwoman, Senate Committee on Energy and Natural Resources

- **The Honorable Maria Cantwell**
  Ranking Member, Senate Committee on Energy and Natural Resources

- **The Honorable Cory Gardner**
  Chairman, Senate Subcommittee on Energy
  Committee on Energy and Natural Resources

- **The Honorable Joe Manchin III**
  Ranking Member, Senate Subcommittee on Energy
  Committee on Energy and Natural Resources

- **The Honorable Greg Walden**
  Chairman, House Committee on Energy and Commerce

- **The Honorable Frank Pallone, Jr.**
  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 Randy Weber**
  Chairman, House Subcommittee on Energy
  Committee on Science, Space and Technology

- **The Honorable Marc Veasey**
  Ranking Member, House Subcommittee on Energy
  Committee on Science, Space and Technology

- **The Honorable Thad Cochran**
  Chairman, Senate Committee on Appropriations

- **The Honorable Patrick Leahy**
  Vice Chairman, Senate Committee on Appropriations

- **The Honorable Lamar Alexander**
  Chairman, Senate Subcommittee on Energy and Water Development
  Committee on Appropriations

- **The Honorable Dianne Feinstein**
  Ranking Member, Senate Subcommittee on Energy and Water Development
  Committee on Appropriations

- **The Honorable Rodney Frelinghuysen**
  Chairman, House Committee on Appropriations

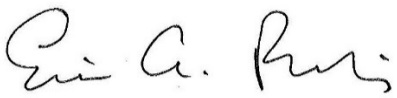
- **The Honorable Nita Lowey**
  Ranking Member, House Committee on Appropriations

- **The Honorable Mike Simpson**
  Chairman, House Subcommittee on Energy and Water Development
  Committee on Appropriations

- **The Honorable Marcy Kaptur**
  Ranking Member, House Subcommittee on Energy and Water Development
  Committee on Appropriations

If you have any questions or need additional information, please contact me or Ms. Shari Davenport, Acting Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,



Dr. Eric Rohlfing
Acting Director
Advanced Research Projects Agency-Energy

# Executive Summary

The Advanced Research Projects Agency-Energy (ARPA-E) invests in technologies that could change the way we use, generate, and store energy. ARPA-E's mission is to advance energy innovations that will create a more secure, affordable, and sustainable American energy future.

ARPA-E creates options for new paths that accelerate the pace of innovation. These developments help our country by:

- Reducing its dependence on energy imports;
- Reducing energy related emissions;
- Improving energy efficiency across all sectors of the economy; and
- Ensuring it maintains a technological lead in developing and deploying advanced energy technologies.

ARPA-E provides America's energy researchers with funding support, technical assistance, and commercialization guidance. This report presents a summary of the activities of ARPA-E during Fiscal Year 2016 (FY 2016).

In FY 2016[1], ARPA-E selected projects for seven programs covering a broad array of energy technologies:

- $7 million under the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program for developing generator technologies that will enable more affordable and efficient residential Combined Heat and Power (CHP) systems (GENSETS SBIR/STTR);
- $125 million for the Agency's third open solicitation (OPEN 2015);
- $33 million for technologies that coordinate load and generation on the grid to create a virtual energy storage system (NODES);
- $11 million for realistic, open-access models and data repositories to aid in improving the U.S. electric grid (GRID DATA);
- $31 million to develop innovative materials that will improve the energy efficiency of existing single-pane windows in commercial and residential buildings (SHIELD);

[1] The GENSETS SBIR/STTR, OPEN 2015, NODES, and GRID DATA FOAs were released in FY2015, with project selections announced in FY2016. The SHIELD, MONITOR Test Site, and IONICS FOAs were released in FY2016, with project selections also announced in FY2016. Funding levels shown on pages iii-9 (inclusive) are as of each program's Project Selection Announcement. The final number of projects and funding amounts are subject to change based on award negotiations and ongoing program management (see Table 2 of this report for updated data on each program).

- $3.5 million to build and operate a testing facility for ARPA-E's MONITOR project teams (MONITOR Test Site)
- $37 million for developing new processing methods and approaches to device integration to accelerate devices built with high performance ion-conducting solids to commercial deployment (IONICS);

ARPA-E released four additional funding opportunities in FY 2016 with project selections that were ultimately announced in FY 2017:

- $34 million to create new control technologies that reduce the energy consumption of future vehicles by using connectivity and vehicle automation (NEXTCAR);
- $33 million to develop technologies that use renewable energy to convert air and water into cost-competitive liquid fuels (REFUEL);
- $35 million for technologies that develop new crop breeding approaches for improved root and soil function that will help plants to store more carbon in the ground and take up nutrients and water more efficiently (ROOTS);
- $25 million for creating innovative components to increase the energy efficiency of datacenters (ENLITENED).

ARPA-E also continued the use of a rolling open solicitation to quickly support innovative applied energy research that has the potential to lead to new focused programs.

In addition to these new programs, ARPA-E hosted the seventh annual Energy Innovation Summit from February 29 to March 2, 2016. The Summit brought together leaders from academia, government, and business to discuss the foremost energy issues, showcase the latest technology innovations, and cultivate relationships to help advance cutting-edge technologies to market. The event drew over 2,000 attendees and featured over 80 speakers and keynote addresses. At the Summit, ARPA-E announced that 36 project teams have formed new companies, 60 projects have partnered with other government agencies for further development and an ever increasing number of technologies have already been incorporated into products that are being sold in the market. Additionally, 45 ARPA-E project teams have attracted more than $1.25 billion in private-sector follow-on funding.

In FY 2016, ARPA-E continued to focus on providing awardees with practical training and critical business information as part of the Agency's Technology-to-Market program. This support equips projects with a clear understanding of market needs to guide technical development and help projects succeed in the marketplace.

# ARPA-E ANNUAL REPORT FOR FISCAL YEAR 2016

## Table of Contents

# I. Legislative Language

This report is in response to the requirements set forth in the America COMPETES Act, Public Law 110-69, section 5012(g)(1)(2007) as amended, which has been codified as 42 U.S.C. § 16538(h)(1), wherein it is stated:

> *"…the Director shall provide to the relevant authorizing and appropriations committees of Congress a report describing projects supported by ARPA-E during the previous fiscal year."*

ARPA-E focuses on energy technologies that can be meaningfully advanced with a modest investment over a defined period of time. ARPA-E's rigorous program design, competitive project selection process, and hands-on engagement, provide America's energy researchers with funding, technical assistance, and market awareness. In FY 2016, ARPA-E thoroughly reviewed all applications and technologies to ensure that investments are made in areas not currently undertaken by industry or other DOE applied research and development investment.

# II. Fiscal Year 2016 Appropriation

The Consolidated Appropriations Act of 2016 (P.L. 114-113) included $291 million in FY 2016 funds for ARPA-E.

# III. Funding Opportunity Announcements (FOAs)

In FY 2016, ARPA-E released seven Funding Opportunity Announcements (FOA). Six FOAs were designed to advance innovative energy technologies in specific program areas; one FOA was created to develop a testing facility for ARPA-E's MONITOR projects.

Project selections for three of these FOAs, as well as four FOAs released in FY 2015, were announced in FY 2016. Selections for four FY 2016 FOAs were announced in FY 2017. The focused technology programs created by these solicitations provide a unique bridge from basic science to early stage technology. They draw from the latest scientific discoveries and will help create a viable path to commercial implementation through firm grounding in the economic realities and changing dynamics of the marketplace.

| TABLE 1: Summary of ARPA-E FOAs Released and/or Awarded in FY 2016[2] | | | | | | |
|---|---|---|---|---|---|---|
| **Program** | **Project Selection** | **Project Selection FY** | **FOA Issuance** | **FOA Issuance FY** | **NUMBER OF PROJECTS** | **FUNDING AMOUNT ($ Million)[2]** |
| **ENLITENED** | 1/24/2017 | FY 2017 | 6/10/2016 | FY 2016 | 9 | $25 |
| **ROOTS** | 12/15/2016 | FY 2017 | 4/12/2016 | FY 2016 | 10 | $35 |
| **REFUEL** | 12/15/2016 | FY 2017 | 4/26/2016 | FY 2016 | 16 | $35 |
| **NEXTCAR** | 11/2/2016 | FY 2017 | 4/12/2016 | FY 2016 | 11 | $34 |
| **IONICS** | 9/13/2016 | FY 2016 | 2/26/2016 | FY 2016 | 16 | $37 |
| **MONITOR Field Test Site** | 6/10/2016 | FY 2016 | 2/26/2016 | FY 2016 | 1 | $3.5 |
| **SHIELD** | 5/18/2016 | FY 2016 | 10/7/2015 | FY 2016 | 14 | $31 |
| **GRID DATA** | 1/15/2016 | FY 2016 | 6/18/2015 | FY 2015 | 7 | $11 |
| **NODES** | 12/11/2015 | FY 2016 | 2/5/2015 | FY 2015 | 12 | $33 |
| **OPEN 2015** | 11/23/2015 | FY 2016 | 1/7/2015 | FY 2015 | 41 | $125 |
| **GENSETS SBIR/STTR** | 10/7/2015 | FY 2016 | 7/16/2015 | FY 2015 | 3 | $7 |
| **Total (Projects Selected)** | | | | | 140 | $376.5 |

## Summary of FY 2016 Project Selections

In FY 2016, selections were announced for 94 projects across seven technology programs:

- On October 7, 2015, ARPA-E announced that three projects were selected to receive $7 million for **GENSETS SBIR/STTR** (*Generators for Small Electrical and Thermal Systems Small Business Innovation Research and Small Business Technology Transfer*)
- On November 23, 2015, ARPA-E announced that 41 projects were selected to receive $125 million for **OPEN 2015**.
- On December 11, 2015, ARPA-E announced that 12 projects were selected to receive $33 million for **NODES** *(Network Optimized Distributed Energy Systems).*
- On January 15, 2016, ARPA-E announced seven projects were selected to receive $11 million for **GRID DATA** *(Generating Realistic Information for the Development of Distribution and Transmission Algorithms).*
- On May 18, 2016, ARPA-E announced 14 projects were selected to receive $31 million for **SHIELD** *(Single-Pane Highly Insulating Efficient Lucid Designs).*

[2] Funding levels shown in this chart are as of each program's Project Selection Announcement. The final number of projects and final funding amounts are subject to change based on award negotiations and ongoing program management (see Table 2 of this report for updated data on each program).

- On June 10, 2016, ARPA-E announced one project was selected to receive $3.5 million for the **MONITOR Field Test Site Program**.
- On September 13, 2016 ARPA-E announced 16 projects were selected to receive $37 million for **IONICS** *(Integration and Optimization of Novel Ion-Conducting Solids).*

Throughout FY 2016, ARPA-E continued utilizing **IDEAS** (*Innovative Development in Energy-Related Applied Science*), a rolling open solicitation that allows ARPA-E to quickly support innovative applied energy research that has the potential to lead to new focused programs.

**Summary of FY 2017 Project Selections for FOAs Announced in FY 2016**

In FY 2016 ARPA-E also issued solicitations for four programs with project selections announced in FY 2017:

- On November 2, 2016, ARPA-E announced 11 projects were selected to receive $34 million for **NEXTCAR** *(Next-Generation Energy Technologies for Connected and Automated On-Road Vehicles).* The FOA was issued on April 12, 2016.
- On December 15, 2016, ARPA-E announced 26 projects were selected to receive $70 million: $35 million for **ROOTS** *(Rhizosphere Observations Optimizing Terrestrial Sequestration)* and $35 million for **REFUEL** *(Renewable Energy to Fuels through Utilization of Energy-dense Liquids).* The FOAs were issued on April 12 and April 26, 2016 respectively.
- On January 24, 2017 ARPA-E selected 9 projects to receive $25 million for **ENLITENED** *(Energy Efficient Light-Wave Integrated Technology Enabling Networks That Enhance Datacenters).* The FOA was issued on June 10, 2016.

**Details on the FY 2016 Project Selections**

The details of the focused programs with project selections announced during FY 2016 are:[3]

- **GENSETS: *Generators for Small Electrical and Thermal Systems* SBIR/STTR ($7 million)**
    - ARPA-E announced three new projects under the SBIR and STTR program. These SBIR/STTR projects are part of the GENSETS program which aims to develop transformative generator technologies to enable widespread deployment of residential CHP systems. These small, natural gas-fueled systems can fulfill most of a U.S. household's electricity and hot water needs, and if widely used

[3] Project counts and funding amounts on pages iii-9 (inclusive) reflect information at the time of the project Selection Announcement. The final number of projects and final funding amounts are subject to change based on contract negotiations and ongoing program management (see Table 2 of this report for updated data on each program).

could increase the overall efficiency of power generation in the United States, and reduce greenhouse gas emissions.

- ***Example GENSETS SBIR/STTR Project: Sencera Energy, Inc. – "Kinematic Flexure-Based Stirling-Brayton Hybrid Engine Generator for Residential CHP" – Charlotte, NC ($1.7 million).*** Sencera Energy, Inc., will develop a novel kinematic Stirling-Brayton hybrid engine using flexure based volume displacement in lieu of conventional displacer and power pistons. The flexure-based design achieves the same function as a piston-cylinder set by simply changing the volume of the working spaces, as opposed to sliding a piston along the interior of a cylinder. The removal of pistons from the design eliminates the need for sliding seals such as piston rings or air/gas bearings, resulting in lower engine friction and fluid flow losses. It also potentially lowers the fabrication cost compared to other heat engines. The proposed kinematic engine design provides easy coupling to existing rotary alternator design, which allows the use of robust and mature off-the-shelf alternator technologies and controllers.

- **NODES:** ***Network Optimized Distributed Energy Systems*** **($33 million)**
  - The NODES program aspires to enable renewables penetration at the 50% level or greater, by developing transformational grid management and control methods to create a virtual energy storage system based on use of flexible load and distributed energy resources (DERs). The challenge is to cost-effectively and reliably manage dynamic changes in the grid by leveraging these additional grid resources, while maintaining customer quality of service. The expected benefits include reduced periods of costly peak demand, reduced energy waste, and increased penetration of renewable energy production. The NODES Program will bring together different scientific communities such as power systems, control systems, computer science, and distributed systems to accelerate the development of new technologies enabling active control of load and DERs in coordination with the grid.
  - ***Example NODES Project: The University of Vermont – "Packetized Energy Management: Coordinating Transmission and Distribution" – Burlington, VT ($1.5 million).*** The University of Vermont (UVM) will develop and test a new approach for demand-side management called packetized energy management (PEM) that builds on approaches used to manage data in communication networks without centralized control and requires a high level of privacy. The PEM system will allow millions of small end-use devices to cooperatively balance energy supply and demand in real time without jeopardizing the reliability of the grid or the quality of service to consumers. The project will develop the PEM method to manage large, rapid fluctuations associated with renewable power generation, while simultaneously ensuring grid reliability. To ensure UVM's PEM method, the integrated system will undergo extensive simulation testing with large-scale hardware implementation for the bulk power grid and in industry-scale, micro-grid environments.

- **GRID DATA:** ***Generating Realistic Information for the Development of Distribution and Transmission Algorithms*** **($11 million)**
    - The GRID DATA program will fund the development of large-scale, realistic, validated, and open-access power system network models. These models will have the detail required to allow the successful development and testing of transformational power system optimization and control algorithms, including new optimal power flow (OPF) algorithms. Project teams will take one of two tracks to develop models. The first option is to partner with a utility to collect and then anonymize real data as the basis for a model that can be released publically. The second approach is to construct purely synthetic power system models. The program will also fund the creation of an open-access, self-sustaining repository for the storage, annotation, and curation of these power systems models, as well as others generated by the community.
    - ***Example GRID DATA Project: The University of Illinois at Urbana-Champaign – "Synthetic Data for Power Grid R&D" – Champaign, IL ($1 million).*** The University of Illinois at Urbana-Champaign, with partners from Cornell University, Virginia Commonwealth University, and Arizona State University will develop 10 open-source and synthetic transmission system models and associated scenarios that match the complexity of power grids. By utilizing statistics derived from real data, the team's models will have coordinates based on North American geography with network structure, characteristics, and consumer demand that mimics real grid profiles. Much of the developed software will be open source and available on the MATPOWER software suite as well as the GRID DATA repository.

- **SHIELD:** ***Single-Pane Highly Insulating Efficient Lucid Designs*** **($31 million)**
    - The SHIELD Program aims to develop innovative materials that will improve the energy efficiency of existing single-pane windows in commercial and residential buildings. Technologies created through the SHIELD program seek to cut in half the amount of heat lost through single-pane windows in cold weather. These materials would improve insulation, reduce cold weather condensation, and enhance occupant comfort. The technologies could also produce secondary benefits, such as improved soundproofing, that will make retrofits more desirable to building occupants and owners. The program will focus on three technical categories: products that can be applied onto existing windowpanes; manufactured windowpanes that can be installed into the existing window sash that holds the windowpane in place; and other early-stage, highly innovative technologies that can enable products in the first two technical categories.
    - ***Example SHIELD Project: NanoSD, Inc. – "Retrofittable and Transparent Super-Insulator for Single-Pane Windows" – San Diego, CA ($3 million).*** NanoSD, Inc. is developing a transparent, nanostructured film that can be applied onto existing single-pane windows to reduce heat loss. The team's material

features unique nanoshell structures that are tightly packed to create a strong thermal barrier. The team will apply a low-emissivity coating to further enhance the material's ability to insulate and incorporate materials to reduce abrasion and condensation. To enable cost-effective fabrication of the product, NanoSD will focus on incorporating all of these steps into a roll-to-roll manufacturing technique.

- **MONITOR (*Methane Observation Networks with Innovative Technology To Obtain Reductions*) Test Site ($3.5 million)**
    - In order to evaluate the performance of each MONITOR technology to locate and quantify fugitive methane emissions, the MONITOR Field Test Site will develop a representative test facility that simulates real-world natural gas operations – at the wellpad and further downstream. Specifically, the MONITOR Test Site supports the operation of a multi-user field test site for MONITOR performers to validate performance under realistic use-case scenarios – and meet the MONITOR program's required metrics related to localization, quantification, communications, and cost. Data generated during the field tests will demonstrate the performance capabilities of the technologies and could be used by the MONITOR performers to accelerate the commercialization and/or regulatory approval of their technologies.
    - ***Example Monitor Test Site Project: Colorado State University – "Test Facility and Proving Ground for ARPA-E MONITOR" – Fort Collins, CO ($3.5 million).*** Colorado State University (CSU) will lead the development of a test site facility at CSU where MONITOR project teams can evaluate their methane sensing technologies. The CSU team will design, construct, and operate a test site that includes multiple sub-facilities simulating a broad range of natural gas production and transmission equipment and operations including: dry and wet gas production, midstream compression, metering and regulating stations, and underground pipelines. The site will feature controlled methane emissions that are realistic in location, frequency, duration, composition, and volume. The CSU site will be located outside of operating oil and natural gas basins allowing for near-complete control of background and onsite emissions. The CSU team includes experts in emissions measurements, natural gas systems testing, and atmospheric dispersion modeling.
- **IONICS: *Integration and Optimization of Novel Ion-Conducting Solids* ($37 million)**
    - Today's growing demand for electricity from carbon-free, renewable resources and for alternatives to petroleum as a transportation fuel has led to a strong desire for cost-effective and durable energy storage and conversion products. The projects that make up ARPA-E's IONICS program are paving the way for technologies that overcome the limitations of current battery and fuel cell products by creating high performance separators and electrodes built with solid ion conductors. The program will focus on developing new processing methods

and approaches to device integration to accelerate devices built with high performance ion-conducting solids to commercial deployment.

- ***Example IONICS Project: Washington University in St. Louis – "Reinforced AEM Separators Based on Triblock Copolymers for Electrode-Decoupled RFBs" – St. Louis, MO ($2 million).*** The Washington University in St. Louis team will use readily available and inexpensive commercial polymers to create a membrane for use in redox flow batteries. The team will investigate possibilities with four types of membrane construction with the goal of achieving the high thermal, chemical, and mechanical stability necessary for use in applications like flow batteries that contain materials like acids. A highly charged nanopowder will be used to improve the conductivity of the membrane while simultaneously increasing its selectivity.

Table 2 on the following page summarizes ARPA-E's programs to date. A full list of the projects selected during FY 2016 can be found in Appendix I. Additional information related to these projects is on ARPA-E's website: http://arpa-e.energy.gov.

| TABLE 2: ARPA-E PROGRAMS TO DATE | | | |
|---|---|---|---|
| **PROGRAM NAME** | | **NUMBER OF PROJECTS** | **FUNDING AMOUNT ($ Million)[4]** |
| **EXISTING PROGRAMS** | OPEN 2009 | 41 | $176 |
| | Batteries for Electrical Energy Storage in Transportation (BEEST) | 12 | $39 |
| | Innovative Materials and Processes for Advanced Carbon Capture Technologies (IMPACCT) | 15 | $41 |
| | Electrofuels | 13 | $49 |
| | Agile Delivery of Electrical Power Technology (ADEPT) | 14 | $38 |
| | Building Energy Efficiency Through Innovative Thermodevices (BEETIT) | 17 | $39 |
| | Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS) | 16 | $44 |
| | Plants Engineered to Replace Oil (PETRO) | 10 | $56 |
| | High Energy Advanced Thermal Storage (HEATS) | 15 | $39 |
| | Rare Earth Alternatives in Critical Technologies (REACT) | 14 | $40 |
| | Green Electricity Network Integration (GENI) | 15 | $44 |
| | Solar Agile Delivery of Electrical Power Technology (Solar ADEPT) | 7 | $14 |
| | Methane Opportunities for Vehicular Energy (MOVE) | 13 | $45 |
| | Advanced Management and Protection of Energy Storage Devices (AMPED) | 14 | $34 |
| | OPEN 2012 | 66 | $179 |
| | Innovative Development in Energy-related Applied Science (IDEAS) | 41 | $23 |
| | Robust Affordable Next Generation Energy Storage Systems (RANGE) | 24 | $46 |
| | Reducing Emissions using Methanotrophic Organisms for Transportation Energy (REMOTE) | 15 | $39 |
| | Modern Electro/Thermochemical Advancements for Light-metal Systems (METALS) | 19 | $45 |
| | Full-Spectrum Optimized Conversion and Utilization of Sunlight (FOCUS) | 14 | $37 |
| | Strategies for Wide Bandgap, Inexpensive Transistors for Controlling High Efficiency Systems (SWITCHES) & SBIR/STTR | 14 | $35 |

[4] Funding levels shown in this chart are as of February 2017 unless otherwise stated. NEXTCAR, REFUEL, ROOTS, and ENLITENED project counts and funding amounts reflect information at the time of selection. Final number of projects and funding amounts are subject to change based on award negotiations.

| | | | |
|---|---|---|---|
| | Reliable Electricity Based on ELectrochemical Systems (REBELS) | 13 | $34 |
| | Cycling Hardware to Analyze and Ready Grid-Scale Electricity Storage (CHARGES)[5] | 2 | $7 |
| | Delivering Efficient Local Thermal Amenities (DELTA) | 11 | $30 |
| | Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR) | 12 | $36 |
| | Accelerating Low-cost Plasma Heating and Assembly (ALPHA) | 9 | $35 |
| | Advanced Research In Dry cooling (ARID) | 14 | $30 |
| | GENerators for Small Electrical and Thermal Systems (GENSETS) | 11 | $26 |
| | Transportation Energy Resources from Renewable Agriculture (TERRA) | 6 | $37 |
| | Traveler Response Architecture using Novel Signaling for Network Efficiency in Transportation (TRANSNET) | 5 | $15 |
| | Micro-scale Optimized Solar-cell Arrays with Integrated Concentration (MOSAIC) | 10 | $25 |
| **FY 2015 FOA / FY 2016 Project Selection** | GENerators for Small Electrical and Thermal Systems Small Business Innovation Research / Small Business Technology Transfer (GENSETS SBIR / STTR) | 3 | $7 |
| | OPEN 2015 | 41 | $125 |
| | Network Optimized Distributed Energy Systems (NODES) | 12 | $33 |
| | Generating Realistic Information for the Development of Distribution and Transmission Algorithms (GRID DATA) | 7 | $11 |
| **FY 2016 FOA and Project Selection** | Single-Pane Highly Insulating Efficient Lucid Design (SHIELD) | 14 | $31 |
| | MONITOR Test Site | 1 | $4 |
| | Integration and Optimization of Novel Ion-Conducting Solids (IONICS) | 16 | $37 |
| **FY2016 FOA / FY 2017 Project Selection** | Next-Generation Energy Technologies for Connected and Automated On-Road Vehicles (NEXTCAR) | 11 | $34 |
| | Renewable Energy to Fuels Through Utilization of Energy-Dense Liquids (REFUEL) | 16 | $35 |
| | Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS) | 10 | $35 |

[5] The GENSETS SBIR/STTR, OPEN 2015, NODES, and GRID DATA FOAs were released in FY2015, with project selections announced in FY2016. The SHIELD, MONITOR Test Site, and IONICS FOAs were released in FY2016, with project selections also announced in FY2016. The NEXTCAR, REFUEL, ROOTS, and ENLITENED FOAs were issued in FY 2016, with project selections in FY 2017.

| | | | |
|---|---|---|---|
| | Energy-Efficient Light-Wave Integrated Technology Enabling Networks that Enhance Datacenters (ENLITENED) | 9 | $25 |
| | Total To Date[6] | 640 | $1.7B |

[6] As of early February 2017 including estimated values for selected projects within the NEXTCAR, REFUEL, ROOTS, and ENLITENED programs.

# IV. ARPA-E Energy Innovation Summit

The seventh annual ARPA-E Energy Innovation Summit took place February 29 to March 2, 2016 at the Gaylord National Convention Center at the National Harbor in Maryland. The Summit convened leaders from academia, business, and government to discuss the foremost energy issues, showcased cutting-edge energy technologies, and facilitated relationships to help move technologies into the market.

Throughout the three-day event, attendees also had the opportunity to explore the Technology Showcase, which featured ARPA-E awardees and a highly selective group of other companies, stakeholders, and research organizations. Many of the transformational energy technologies displayed in the Technology Showcase were demonstrated publically for the first time.

***ARPA-E Energy Innovation Summit Highlights***

- Over 2,000 registered attendees from across the United States and 25 countries
- Technology Showcase displaying more than 270 breakthrough energy technologies from ARPA-E awardees and other innovative companies
- Dynamic panel discussions and networking sessions that enabled participants to meet with ARPA-E Program Directors, global industry leaders, and energy technologists
- Over 80 expert speakers and keynote addresses, including leaders from government, business, and academia
- Attendance and comments by a bipartisan group of United States senators and representatives
- Announcement that as of early 2016, ARPA-E had recognized several notable accomplishments, including:
    - At least 36 ARPA-E project teams have formed new companies to advance their technologies
    - 60 ARPA-E project teams have partnered with other government agencies for further development
    - 45 ARPA-E project teams have attracted more than $1.25 billion in private-sector follow-on funding.

# V. Conclusion

In FY 2016, ARPA-E announced project selections for six focused programs and one open program. The programs created through these solicitations cover a wide range of technical areas:[7]

- IONICS: paving the way for technologies that overcome the limitations of current battery and fuel cell products;
- MONITOR Field Test Site: development of a simulated, but realistic natural gas test site for use by MONITOR Awardees;
- SHIELD: development of innovative window coatings and windowpanes that could significantly improve the energy efficiency of existing single-pane windows in commercial and residential buildings;
- GRID DATA: development of realistic, open-access models and data repositories to aid in improving the U.S. electric grid;
- NODES: development of technologies that coordinate load and generation on the grid to create a virtual energy storage system;
- OPEN 2015: the Agency's third open solicitation;
- GENSETS SBIR/STTR: development of generator technologies to enable more affordable and efficient residential CHP systems.

As directed by its statutory authorization,[8] ARPA-E entered into a contract with the National Academy of Sciences in October 2014 to "conduct an evaluation of how well ARPA-E is achieving the goals and mission of ARPA-E." ARPA-E has and will continue to actively engage with the National Academies *ad hoc* committee preparing this report[9].

As of February 2017, ARPA-E has invested over $1.5 billion across more than 580 projects through 36 focused programs and three open funding solicitations (OPEN 2009, OPEN 2012, and Open 2015).[10]

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[7] The GRID DATA, NODES, OPEN 2015, and GENSETS SBIR/STTR FOAs were released in FY 2015, with project selections announced in FY 2016. The IONICS, MONITOR Field Test, and SHIELD FOAs were released in FY 2016, with project selections also announced in FY 2016.

[8] Public Law 110-69, section 5012(k)(2007) as amended, which has been codified as 42 U.S.C. § 16538(l)

[9] More information on the report being prepared by the National Academies is available on their website. As of February 2017, the National Academies expects the study to be published by June 2017. http://sites.nationalacademies.org/PGA/step/ARPA-E_Evaluation/index.htm

[10] This statement does not include selected projects which have not yet completed contracting as of early February, 2017 (i.e. several projects within the NEXTCAR, REFUEL, ROOTS, and ENLITENED programs).

At the 2016 ARPA-E Energy Innovation Summit, the Agency convened a diverse and influential group of energy experts and industry leaders focused on advancing the next generation of breakthrough energy technologies. The Summit brought together leaders with unique perspectives, experiences, and ideas with the shared goal of revolutionizing the American approach to energy innovation.

The statutory goals of ARPA-E are to enhance the economic and energy security of the United States through the development of technologies that reduce America's dependence on energy imports; reduce U.S. energy related emissions; improve energy efficiency across all sectors of the U.S. economy; and ensure the United States maintains a technological lead in the development and deployment of advanced energy technologies.

In FY 2016, ARPA-E Program Directors provided awardees with technical guidance and developed new programs by engaging diverse communities to identify gaps where investment by ARPA-E could lead to transformational technologies enabling entirely new ways to generate, store, and use energy. The ARPA-E technology-to-market program provides practical training and business information to equip awardees with a clear understanding of market needs to guide technical development.

# VI. Appendix I: Projects Selected in FY 2016

Data below is as of the dates on which project selections were publicly announced:

October 7, 2015 (GENSETS SBIR/STTR); November 23, 2015 (OPEN 2015); December 11, 2015 (NODES); January 15, 2016 (GRID DATA); May 18, 2016 (SHIELD & SHIELD SBIR/STTR); June 10, 2016 (MONITOR Field Test Site); and September 13, 2016 (IONICS).

Additional information on these projects is available on the ARPA-E website: http://arpa-e.energy.gov.

| PROGRAM | LEAD ORGANIZATION | PROJECT TITLE | LOCATION | ARPA-E FUNDING [11] (Million $) |
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| GENSETS SBIR/STTR | Sencera Energy, Inc. | Kinematic Flexure-Based Stirling-Brayton Hybrid Engine Generator for Residential CHP | Charlotte, NC | $1,754,452 |
| GENSETS SBIR/STTR | Air Squared, Inc. | A High Efficiency SACI 1kW Generator with Organic Rankine Cycle Waste Heat Recovery | Broomfield, CO | $2,745,000 |
| GENSETS SBIR/STTR | Mohawk Innovative Technology, Inc. | High-Speed Microturbine with Air Foil Bearings for Residential CHP | Albany, NY | $2,500,000 |
| OPEN 2015 | Case Western Reserve University | Data Analytics for Virtual Energy Audits and Value Capture Assessments of Buildings | Cleveland, OH | $1,433,281 |
| OPEN 2015 | University of California, Santa Barbara | High-Efficiency, Low Cost Laser-Based Solid State Lighting | Santa Barbara, CA | $2,372,724 |
| OPEN 2015 | The Mackinac Technology Company | Retrofit System for Single Pane Window Efficiency | Grand Rapids, MI | $2,500,000 |
| OPEN 2015 | University of Colorado Boulder | Paintable Heat-Reflective Coatings for Low-Cost Energy Efficient Windows | Boulder, CO | $3,955,218 |
| OPEN 2015 | Boston Electrometallurgical Corporation | Revolutionary Process for Low-Cost Titanium | Natick, MA | $2,279,027 |

[11] Figures represent funding amounts at the time of project announcements. Final amounts are subject to change based on award negotiations. Please see the ARPA-E's website for updated information: http://arpa-e.energy.gov/.

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| OPEN 2015 | Electric Power Research Institute, Inc. | Directional Solvent Extraction – A Low Temperature, Non-Membrane Water Desalination Process using Waste Heat | Palo Alto, CA | $1,500,000 |
| OPEN 2015 | INFINIUM, Inc | Ultra-Low Energy Magnesium Recycling for New Light-Weight Vehicles | Natick, MA | $2,850,000 |
| OPEN 2015 | Oak Ridge National Laboratory | New High Temperature, Corrosion-Resistant Cast Alloy For Operation in Industrial Gaseous Environments | Oak Ridge, TN | $3,900,000 |
| OPEN 2015 | RedWave Energy, Inc | High Speed Diode and Rectenna for Waste Heat to Electricity Harvesting | Glen Ellyn, IL | $3,381,448 |
| OPEN 2015 | Stanford University | High Efficiency Wafer-Scale Thermionic Energy Converters | Stanford, CA | $3,636,000 |
| OPEN 2015 | Gas Technology Institute | Reactor Engine | Des Plaines, IL | $3,000,000 |
| OPEN 2015 | Princeton Optronics | Low Power Consumption, Ultra-High Speed VCSELs for Optical Communication | Trenton, NJ | $1,120,000 |
| OPEN 2015 | University of California, Santa Barbara | High Efficiency Quantum-Dot Photonic Integrated Circuit Technology Epitaxially Grown on Silicon | Santa Barbara, CA | $1,935,325 |
| OPEN 2015 | Accio Energy, Inc. | EHD Innovative Low-Cost Offshore Wind Energy | Ann Arbor, MI | $4,500,000 |
| OPEN 2015 | University of Virginia | 50 MW Segmented Ultralight Morphing Rotors for Wind Energy | Charlottesville, VA | $3,569,580 |
| OPEN 2015 | National Renewable Energy Laboratory | Ultrahigh Efficiency Photovoltaics at Ultralow Costs | Golden, CO | $5,160,000 |
| OPEN 2015 | Ocean Renewable Power Company | Tidal Power: Deployment and Retrieval System for Cross-flow Hydrokinetic Turbines | Portland, ME | $2,248,223 |
| OPEN 2015 | Cummins Corporate Research & Technology | Efficient Knock Suppression in Spark Ignited Engines | Columbus, IN | $2,073,235 |
| OPEN 2015 | Ceramatec, Inc | Electrochemical Ammonia Synthesis for Grid Scale Energy Storage | Salt Lake City, UT | $2,350,000 |

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| OPEN 2015 | Dioxide Materials, Inc. | High Efficiency Alkaline Water Electrolyzers for Grid Scale Energy Storage | Boca Raton, FL | $2,000,000 |
| OPEN 2015 | Oak Ridge National Laboratory | Hydration-Free Conductive Membranes Based on Two Dimensional Materials | Oak Ridge, TN | $2,800,000 |
| OPEN 2015 | Iowa State University | Low Cost, Safe, and Efficient All Solid State Sodium Batteries for Grid-scale Energy Storage and Other Applications | Ames, IA | $2,949,872 |
| OPEN 2015 | General Electric Company, GE Global Research | Charge-Balanced SiC FETs for Breakthrough Power Conversion | Niskayuna, NY | $2,561,606 |
| OPEN 2015 | Tibbar Technologies | Plasma-based AC-DC Transformer for HVDC Transmission | Los Alamos, NM | $3,500,000 |
| OPEN 2015 | Pacific Northwest National Laboratory | High Performance Power-grid Optimization (HIPPO) for Flexible and Reliable Resource Commitment Against Uncertainties | Richland, WA | $3,120,249 |
| OPEN 2015 | University of Tennessee, Knoxville | A Smart and Flexible Microgrid with a Low-cost Scalable Open-source Controller | Knoxville, TN | $2,400,000 |
| OPEN 2015 | ProsumerGrid, Inc | Distribution System Operator Simulation Studio | Atlanta, GA | $3,000,000 |
| OPEN 2015 | Vanderbilt University | Resilient Information Architecture Platform for the Smart Grid | Nashville, TN | $3,500,000 |
| OPEN 2015 | Newton Energy Group, LLC | Coordinated Operation of Electric and Natural Gas Supply Networks: Optimization Processes and Market Design | Boston, MA | $2,904,745 |
| OPEN 2015 | Achates Power, Inc. | Gasoline Compression Ignition Medium Duty Multicylinder Opposed Piston Engine Development | San Diego, CA | $9,002,986 |
| OPEN 2015 | University of Michigan | Split Micro-hybrid Boosting Enabling Highly Diluted Combustion | Ann Arbor, MI | $1,923,845 |
| OPEN 2015 | Corning Incorporated | Roll-to-Roll Processing Ceramic Battery Electrolyte | Corning, NY | $3,102,359 |
| OPEN 2015 | University of Michigan | Transitioning Advanced Ceramic Electrolytes into Manufacturable Solid-State EV Batteries | Ann Arbor, MI | $3,500,000 |

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| OPEN 2015 | Proton Energy Systems | Dual Mode Energy Conversion and Storage Flow Battery | Wallingford, CT | $2,500,000 |
| OPEN 2015 | Pajarito Powder, LLC | Precious Metal Free Regenerative Hydrogen Electrode for Fuel-Cell Vehicles | Albuquerque, NM | $2,790,000 |
| OPEN 2015 | Oregon State University | Converting Biogas to Liquid Fuels by Low Energy Electrical Corona Discharge Processes | Corvallis, OR | $2,256,677 |
| OPEN 2015 | Starfire Energy | Ammonia Synthesis for Fuel, Energy Storage, and Agriculture Applications | Aurora, CO | $1,424,691 |
| OPEN 2015 | Marine BioEnergy, Inc | Disruptive Supplies of Affordable Biomass Feedstock Grown in the Open Ocean | San Diego, CA | $2,146,988 |
| OPEN 2015 | Texas A&M AgriLife Research | Developing Ground Penetrating Radar (GPR) for Enhanced Root and Soil Organic Carbon Imaging: Optimizing Bioenergy Crop Adaptation and Agro-ecosystem Services | College Station, TX | $4,600,000 |
| OPEN 2015 | University of Illinois at Urbana-Champaign | Novel Technologies to Solve the Water Use Problem of High Yielding C4 Bioenergy and Bioproduct Feedstocks | Urbana, IL | $4,995,967 |
| OPEN 2015 | University of Tennessee, Knoxville | SynPLASTome 2.0: Synthetic Plastid Genome to Reprogram Chloroplast Function for the Production of Fuels and Chemicals | Knoxville, TN \| | $3,500,000 |
| NODES | University of Vermont | Packetized Energy Management: Coordinating Transmission and Distribution | Burlington, VT | $1,537,904 |
| NODES | University of California: San Diego | Distributed Grid Control of Flexible Loads and DERs for Optimized Provision of Synthetic Regulating Reserves | La Jolla, CA | $2,338,485 |
| NODES | Arizona State University | Stochastic Optimal Power Flow for Real-Time Management of Distributed Renewable Generation and Demand Response | Tempe, AZ | $3,000,000 |
| NODES | Stanford University | Open and Scalable Distributed Energy Resource Networks | Stanford, CA | $3,500,000 |

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| NODES | General Electric Global Research | Synthetic Reserves from Aggregated Distributed Flexible Resources | Niskayuna, NY | $3,900,000 |
| NODES | National Renewable Energy Laboratory | Real-time Optimization and Control of Next-Generation Distribution Infrastructure | Golden, CO | $3,900,000 |
| NODES | Pacific Northwest National Laboratory | Multi-scale Incentive-Based Control of Distributed Assets | Richland, WA | $2,700,000 |
| NODES | Regents of the University of Minnesota | A Robust Distributed Framework for Flexible Power Grids | Minneapolis, MN | $2,950,000 |
| NODES | Northwestern University | A Novel Hierarchical Frequency-Based Load Control Architecture | Evanston, IL | $2,692,845 |
| NODES | DNV GL | Enabling the Internet of Energy through Network Optimized Distributed Energy Resources | Chalfont, PA | $2,150,000 |
| NODES | National Rural Electric Cooperative Association | GridBallast - Autonomous Load Control for Grid Resilience | Arlington, VA | $1,335,507 |
| NODES | Eaton Corporation | Cloud-Based Cascaded Multi-rate DER Control for Synthetic Regulating Reserves | Menomonee Falls, WI | $3,311,532 |
| GRID DATA | National Renewable Energy Laboratory | SMARtDaTa: Standardized Multi-Scale Models of Anonymized Realistic Distribution and Transmission Data | Golden, CO | $2,300,000 |
| GRID DATA | The University of Michigan | High Fidelity, Year Long Power Network Data Sets for Replicable Power System Research | Ann Arbor, MI | $1,418,845 |
| GRID DATA | University of Illinois at Urbana-Champaign | Synthetic Data for Power Grid R&D | Champaign, IL | $1,028,325 |
| GRID DATA | Pacific Northwest National Laboratory | Data Repository for Power System Open Models with Evolving Resources (DR POWER) | Richland, WA | $1,500,108 |
| GRID DATA | GridBright, Inc. | A Standards-Based Intelligent Repository for Collaborative Grid Model Management | Alamo, CA | $1,697,292 |
| GRID DATA | Pacific Northwest National Laboratory | Sustainable Data Evolution Technology for Power Grid Optimization | Richland, WA | $1,484,922 |
| GRID DATA | University of Wisconsin - Madison | EPIGRIDS: Electric Power Infrastructure & Grid Representations in Interoperable Data Sets | Madison, WI | $1,866,788 |

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| SHIELD | Argonne National Laboratory | Self-Assembled Nanocellular Composites with Super Thermal Insulation and Soundproof for Single-Pane Windows | Lemont, IL | $3,102,671 |
| SHIELD | Arizona State University | Single-Pane Windows with Insulating Sprayed Particulate Coatings | Tempe, AZ | $2,197,800 |
| SHIELD | Aspen Aerogels, Inc. | Aerogel Insulated Pane as a Replacement for Panes in Single-Pane Windows | Northborough, MA | $2,751,377 |
| SHIELD | Eclipse Energy Systems, Inc. | Eclipse Shield | Saint Petersburg, FL | $1,249,791 |
| SHIELD | Oak Ridge National Laboratory | Low Cost, Multilayer, Highly Transparent and Thermally Insulating Hybrid Silica-Polymer Film | Oak Ridge, TN | $2,540,000 |
| SHIELD | PARC, a Xerox Company | Scalable Transparent Thermal Barriers for Single-Pane Window Retrofits | Palo Alto, CA | $2,887,312 |
| SHIELD | Regents of the University of California, Los Angeles | THermally INsultating traNsparEnt barrieR (THINNER) Coatings for Single-Pane Windows | Los Angeles, CA | $1,200,000 |
| SHIELD | SRI International | Window Retrofit Applique using Phonon engineering (WRAP) | Menlo Park, CA | $2,968,501 |
| SHIELD | University of California, San Diego | "Thinner Than Air": Polymer-Based Coatings of Single-Pane Windows | La Jolla, CA | $1,400,000 |
| SHIELD | University of Colorado Boulder | Advancing Insulation Retrofits from Flexible Inexpensive Lucid Materials (AIR FILMs) for Single-Pane Windows | Boulder, CO | $1,800,000 |
| SHIELD | Virginia Commonwealth University | Fabrication of Inexpensive, Transparent Aerogel Panes | Richmond, VA | $859,891 |
| SHIELD SBIR/STTR | IR Dynamics, LLC | Dynamic IR Window Film to Improve Window Energy Efficiency | Santa Fe, NM | $1,950,000 |
| SHIELD SBIR/STTR | NanoSD, Inc. | Retrofittable and Transparent Super-Insulator for Single-Pane Windows | San Diego, CA | $3,000,000 |
| SHIELD SBIR/STTR | Triton Systems, Inc. | Energy Efficient Window Thermal Control | Chelmsford, MA | $3,224,500 |
| MONITOR Field Test Site | Colorado State University | Test Facility and Proving Ground for ARPA-E Monitor | Fort Collins, CO | $3,533,836 |

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| IONICS | 24M | Large Area Lithium Electrode Sub-Assemblies (LESAs) Protected by Self-Forming Microstructured Polymer-Inorganic Single-Ion Conducting Composites | Cambridge, MA | $3,500,000 |
| IONICS | Ionic Materials | Novel Polymer Electrolyte for Solid State Lithium Metal Battery Technology | Woburn, MA | $3,000,000 |
| IONICS | Iowa State University | Development and Testing of New, High–Li+ Ion Conductivity Glassy Solid Electrolytes for Lithium Metal Batteries | Ames, IA | $2,250,000 |
| IONICS | Oak Ridge National Laboratory | Metastable and Glassy Ionic Conductors (MAGIC) | Oak Ridge, TN | $3,000,000 |
| IONICS | Pennsylvania State University | Cold-Sintering Composite Structures for Solid Lithium Ion Conductors | University Park, PA | $1,000,000 |
| IONICS | PolyPlus Battery Company | Flexible Solid Electrolyte Protected Li Metal Electrodes | Berkeley, CA | $5,250,000 |
| IONICS | Sila Nanotechnologies | Melt-Infiltration Solid Electrolyte Technology for Solid State Lithium Batteries | Almeda, CA | $1,000,000 |
| IONICS | University of Colorado Boulder | Flash Sintering System for Manufacturing Ion-Conducting Solids | Boulder, CO | $1,000,000 |
| IONICS | Colorado School of Mines | Hybrid Polyoxometalate Membranes for High Proton Conduction with Redox Ion Exclusion | Golden, CO | $1,564,386 |
| IONICS | United Technologies Research Center | Synergistic Membranes and Reactants for a Transformative Flow-Battery System | East Hartford, CT | $2,712,559 |
| IONICS | University of Colorado Boulder | Anion Channel Membranes | Boulder, CO | $3,000,000 |
| IONICS | Washington University in St. Louis | Reinforced AEM Separators Based on Triblock Copolymers for Electrode-Decoupled RFBs | St. Louis, MO | $2,000,000 |
| IONICS | 3M Company | Low Cost, Durable, Commercially Viable Polymeric Anion Exchange Membranes | St. Paul, MN | $2,300,000 |
| IONICS | Rensselaer Polytechnic Institute | Channel Engineering of Hydroxide Ion Exchange Polymers and Reinforced Membranes | Troy, NY | $2,245,327 |

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| IONICS | University of Delaware | Highly Conductive, Stable and Robust Hydroxide Exchange Membranes Based on Poly (Aryl Piperidinium) | Newark, DE | $1,800,000 |
| IONICS | University of California, San Diego | Self-Forming Solid-State Batteries | La Jolla, CA | $1,000,000 |