U.S. DEPARTMENT OF ENERGY

ARPA-E Fiscal Year 2020 Annual Report

Report to Congress
November 2022

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 prepare for the deployment of their technologies.

In Fiscal Year (FY) 2020, we continued developing our diverse portfolio of advanced energy technologies. We issued 13 funding opportunity announcements (FOA), including one to develop digital twin technology to reduce operations and maintenance (O&M) costs in the next generation of nuclear power plants by 10 times in the Generating Electricity Managed by Intelligent Nuclear Assets (GEMINA) program. Moreover, we announced projects ranging from developing low-cost electric aviation engine technology and powertrain systems with the Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives (ASCEND) program to developing technologies to quantify feedstock-related emissions at the field level through the Systems for Monitoring and Analytics for Renewable Transportation Fuels from Agricultural Resources and Management (SMARTFARM) program. In FY 2020, ARPA-E announced and selected a combined 242 projects with $403.5 million dollars in awards.

Many of ARPA-E's project teams have taken steps to advance their technologies toward market impact. As of September 2020, over 1,100 projects have been funded, 88 companies have been formed by ARPA-E projects, 232 projects have partnered with other government agencies for further development, and an ever-increasing number of technologies have been incorporated into products sold in the market. Additionally, 172 ARPA-E project teams have attracted more than $6.3 billion dollars in private-sector follow-on funding to further support the development and commercialization of their technologies and companies.[1] This includes an 'exit valuation' of $3.3 billion dollars for QuantumScape through a reverse merger that represents the enterprise value of the company on the date of its public listing.[2]

Moreover, ARPA-E projects have helped advance scientific understanding and technological innovation through 4,256 peer-reviewed journal articles and 643 patents issued by the U.S. Patent and Trademark Office. These indicators demonstrate that ARPA-E's approach to selecting, funding, and actively managing early-stage energy R&D continues to pay off, advancing the state of the art in energy science and engineering and defining new opportunities for commercialization of advanced energy technologies.

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[1] The 'Follow on Funding' value includes any commercial funding committed or received from other sources (e.g. private investors, venture capital, etc.) after effective date of ARPA-E Award to support the ARPA-E-funded project or work that is directly or indirectly related to the ARPA-E funded project.

[2] In future versions of our impact indicators, the total enterprise valuation number for public listing transactions, acquisitions, and company sales will be reported separately from the 'follow on funding' number. This 'exit valuation' number will include development capital and equity valuation minus cash on hand.

This report is being provided to the following Members of Congress:

- **The Honorable Joe Manchin III**
  Chairman, Senate Committee on Energy and Natural Resources
- **The Honorable John Barrasso**
  Ranking Member, Senate Committee on Energy and Natural Resources
- **The Honorable Mazie K. Hirono**
  Chair, Subcommittee on Energy
  Senate Committee on Energy and Natural Resources
- **The Honorable John Hoeven**
  Ranking Member, Subcommittee on Energy
  Senate Committee on Energy and Natural Resources
- **The Honorable Frank Pallone, Jr.**
  Chairman, House Committee on Energy and Commerce
- **The Honorable Cathy McMorris Rodgers**
  Ranking Member, House Committee on Energy and Commerce
- **The Honorable Eddie Bernice Johnson**
  Chairwoman, House Committee on Science, Space, and Technology
- **The Honorable Frank Lucas**
  Ranking Member, House Committee on Science, Space, and Technology
- **The Honorable Jamaal Bowman**
  Chair, Subcommittee on Energy
  House Committee on Science, Space, and Technology
- **The Honorable Randy Weber**
  Ranking Member, Subcommittee on Energy
  House Committee on Science, Space, and Technology
- **The Honorable Patrick Leahy**
  Chairman, Senate Committee on Appropriations
- **The Honorable Richard Shelby**
  Vice Chairman, Senate Committee on Appropriations
- **The Honorable Dianne Feinstein**
  Chair, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations
- **The Honorable John Kennedy**
  Ranking Member, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations
- **The Honorable Rosa L. DeLauro**
  Chair, House Committee on Appropriations
- **The Honorable Kay Granger**
  Ranking Member, House Committee on Appropriations
- **The Honorable Marcy Kaptur**
  Chairwoman, Subcommittee on Energy and Water Development
  House Committee on Appropriations

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

If you have questions or need additional information, please contact me or Ms. Katie Donley, Deputy Director of External Affairs, Office of the Chief Financial Officer, at 202-586-0176; Mr. Michael Harris, Legislative Affairs Advisor (House), Office of Congressional and Intergovernmental Affairs, at michael.harris2@hq.doe.gov; or Ms. Rebecca Ward, Deputy Assistant Secretary for Senate Affairs, Office of Congressional and Intergovernmental Affairs, at 202-586-5450.

Sincerely,

Dr. Jennifer Gerbi
Acting Director & Deputy Director for Technology
Advanced Research Projects Agency-Energy

Executive Summary

ARPA-E funds technologies that have the potential to change the way to get, store, and use energy. ARPA-E's mission is to advance energy innovations that will create a more secure, affordable, and sustainable American energy future.

ARPA-E focuses on early-stage energy technologies that can be meaningfully advanced with modest funding over a defined time period. 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. Each year, ARPA-E thoroughly reviews all applications and technologies to ensure that funding is provided to topics not likely to be pursued by industry, Federal agencies, or other DOE applied research and development (R&D) programs.

This report presents a chronological summary of the activities of ARPA-E during FY 2020[3], in which ARPA-E selected projects across **14** programs covering a broad array of energy technologies:

1. $15.0 million to accelerate the incorporation of machine learning and artificial intelligence into the energy technology and product design processes for **DIFFERENTIATE** (*Design Intelligence Fostering Formidable Energy Reduction and Enabling Novel Totally Impactful Advanced Technology Enhancements);*
2. $3.2 million in partnership with the Department of Defense (DoD) to further demonstrate and validate ARPA-E-derived technologies at DoD installations across the country for **ESTCP** (*Energy and Carbon Optimized Synthesis for the Bioeconomy)*;
3. $30.5 million to develop innovative management systems that represent the relative delivery risk of each asset, like wind farms or power plants, and balance the collective risk of all assets across the grid for **PERFORM** (*Performance-based Energy Resource Feedback, Optimization, and Risk Management*);
4. $31.7 million to explore new areas of technology for **Solicitation on Topics Informing New Program Areas;**
5. $27.0 million to develop digital twin technology to reduce operations and maintenance (O&M) costs in the next generation of nuclear power plants for **GEMINA** (*Generating Electricity Managed by Intelligent Nuclear Assets*);

[3] The GO Competition Challenge 1 FOA was released in FY 2018 and selected in FY 2020. The DIFFERENTIATE, ESTCP, PERFORM, and Solicitation on Topics Informing New Project Areas (Topics G and H) FOAs were released in FY 2019, with project selections announced in FY 2020. The GEMINA, BETHE, ASCEND, REEACH, SMARTFARM, GAMOW, REPAIR, SCALEUP Fast-Track, FLECCS, and Solicitation on Topics Informing New Project Areas (Topics I – K) FOAs were released in FY 2020, with project selections also in FY 2020. Funding levels shown on pages iv - 44 (inclusive) are as of the date 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). This report includes all FY 2020 programs and projects selected as of October 2020.

6. $35.0 million to support the development of timely, commercially viable fusion energy for **BETHE** (*Breakthroughs Enabling THermonuclear-fusion Energy*);
7. $29.0 million to close multiple fusion-specific technological gaps that will be needed to connect a net-energy-gain "fusion core" to a deployable, commercially attractive fusion system for **GAMOW** (*Galvanizing Advances in Market-aligned fusion for an Overabundance of Watts*);
8. $14.5 million to develop innovative, lightweight, and ultra-efficient all-electric powertrains with advanced thermal management systems that help enable efficient net-zero carbon emissions for single-aisle passenger commercial aircraft for **ASCEND** (*Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives*);
9. $20.0 million to create innovative, cost-effective, and high-performance energy storage and power generation sub-systems for electric aircraft, with a focus on fuel-to-electric power conversion technologies for **REEACH** (Range Extenders for Electric Aviation with Low Carbon and High Efficiency);
10. $16.5 million to develop technologies that bridge the data gap in the biofuel supply chain by quantifying feedstock-related greenhouse gas (GHG) emissions and soil carbon dynamics at the field level for **SMARTFARM** (*Systems for Monitoring and Analytics for Renewable Transportation Fuels from Agricultural Resources and Management*);
11. $33.0 million to develop natural gas transmission pipeline retrofitting technology to rehabilitate existing cast iron and bare steel pipes by creating new, robust pipes inside of old ones for **REPAIR** (*Rapid Encapsulation of Pipelines Avoiding Intensive Replacement*);
12. $3.4 million to accelerate the development of transformational and disruptive methods for solving the nation's most pressing power system problems for **Grid Optimization (GO) Competition Challenge 1**;[4]
13. $11.5 million to develop carbon capture and storage (CCS) processes that better enable technologies, such as natural gas power generators, to be responsive to grid conditions in a high variable renewable energy (VRE) penetration environment for **FLECCS** (*FLExible Carbon Capture and Storage*);
14. $24.0 million to take promising energy technologies to the pre-pilot stage of the path to market and ultimately lead to realized commercial impact for **SCALEUP "Fast Track"** (*Seeding Critical Advances for Leading Energy technologies with Untapped Potential "Fast Track"*).

[4] The GO Competition FOA was announced in FY 2018, with the Challenge 1 awardees selected in FY 2020.

ARPA-E released 4 additional funding opportunities in FY 2020 with project selections that were ultimately announced in FY 2021:

1. $33.2 million to explore new areas of technology for **Solicitation on Topics Informing New Program Areas;**
2. $35.0 million to develop new economically competitive Hydrokinetic Turbines (HKT) designs for tidal and riverine currents for **SHARKS** (*Submarine Hydrokinetic And Riverine Kilo-megawatt Systems*);
3. $16.0 million to develop ultrahigh temperature materials for gas turbine use in the aviation and power generation industries for **ULTIMATE** (*Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency*);
4. $25.0 million to promote the use of advanced synthetic biology tools to engineer novel biomass conversion platforms and systems for **ECOSynBio** (*Energy and Carbon Optimized Synthesis for the Bioeconomy*).

In FY 2020, 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 performers with a clear understanding of market needs to guide technical development and help their projects succeed in the marketplace.

ARPA-E Fiscal Year 2020 Annual Report to Congress

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 early-stage energy technologies that can be meaningfully advanced with modest funding over a defined time period. 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. Each year, ARPA-E thoroughly reviews all applications and technologies to ensure that funding is provided to topics not currently pursued by industry, Federal agencies, or other DOE applied R&D programs.

II. Fiscal Year 2020 Appropriation

The Further Consolidated Appropriations Act, 2020 included $425 million in FY 2020 funds for ARPA-E.

III. Funding Opportunity Announcements

In FY 2020, ARPA-E released 13 FOAs[5] designed to advance innovative energy technologies in specific program areas.

Project selections for 10 of these FOAs[6] released in FY 2020, 4 FOAs[7] released in FY 2019, and 1 FOA released in FY 2018[8], were announced in FY 2020. Four FY 2020 FOAs[9] were selected in FY 2021. The 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.

The below table encompasses FOAs released in FY 2019 with projects selected in FY 2020, FOAs released in FY 2020 with projects selected in FY 2020, and FOAs released in FY 2020 with project selections in FY 2021.

[5] Solicitation on Topics Informing New Program Areas (Topics I-R), GEMINA , BETHE, FLECCS, ASCEND, REEACH, SMARTFARM, GAMOW, REPAIR, SHARKS, SCALEUP, ECOSynBio, and ULTIMATE FOAs were announced in FY 2020.

[6] GEMINA, BETHE, ASCEND, REEACH, SMARTFARM, GAMOW, REPAIR, SCALEUP Fast-Track, FLECCS, and Solicitation on Topics Informing New Program Areas (Topics I-K).

[7] Solicitation on Topics Informing New Project Areas (Topics G and H), DIFFERENTIATE, PERFORM, and ESTCP.

[8] GO Competition 1.

[9] Solicitation on Topics Informing New Program Areas (Topics L – R), SHARKS, ULTIMATE, and ECOSynBio.

TABLE 1: Summary of ARPA-E FOAs Released and Projects Selected in FY 2020						
Program	**FOA Issuance**	**FOA Issuance FY**	**Project Selection**	**Project Selection FY**	**Number of Projects**	**Funding Amount ($ Million)[10]**
GO Competition Challenge 1	7/24/2018	FY 2018	2/12/2020	FY 2020	10	$3.4
DIFFERENTIATE	4/05/2019	FY 2019	11/19/2019	FY 2020	23	$15
ESTCP	4/10/2019	FY 2019	3/17/2020	FY 2020	4	$3.2
Solicitation on Topics Informing New Program Areas (Topic G)	8/07/2019	FY 2019	5/20/2020	FY 2020	17	$8
PERFORM	9/19/2019	FY 2019	5/13/2020	FY 2020	12	$30.5
Solicitation on Topics Informing New Program Areas (Topic H)	9/19/2019	FY 2019	1/09/2020	FY 2020	5	$13.3
GEMINA	10/02/2019	FY 2020	5/13/2020	FY 2020	9	$27
BETHE	11/07/2019	FY 2020	4/07/2020	FY 2020	16	$35
FLECCS[11]	11/14/2019	FY 2020	7/13/2020	FY 2020	12	$11.5
Solicitation on Topics Informing New Program Areas (Topic I)	11/14/2019	FY 2020	4/06/2020	FY 2020	2	$1.4
ASCEND	12/17/2019	FY 2020	8/08/2020	FY 2020	9	$14.5
REEACH	12/17/2019	FY 2020	8/08/2020	FY 2020	9	$20
SCALEUP[12]	12/17/2019	FY 2020	9/16/2020	FY 2020	2	$24
SMARTFARM	12/19/2019	FY 2020	9/09/2020	FY 2020	6	$16.5
GAMOW	2/13/2020	FY 2020	9/02/2020	FY 2020	14	$29
REPAIR	2/18/2020	FY 2020	8/06/2020	FY 2020	10	$33
Solicitation on Topics Informing New Program Areas (Topic J)	3/04/2020	FY 2020	8/25/2020	FY 2020	6	$5
Solicitation on Topics Informing New Program Areas (Topic K)	4/02/2020	FY 2020	9/02/2020	FY 2020	4	$4

[10] Funding levels shown in this chart are as of the date 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).

[11] Selections for Phase 1 only.

[12] Selections for SCALEUP Fast-Track only. Selections for the SCALEUP FOA, under which the SCALEUP Fast-Track selections fall, occurred in FY 2021.

TABLE 1: Summary of ARPA-E FOAs Released and Projects Selected in FY 2020						
Program	**FOA Issuance**	**FOA Issuance FY**	**Project Selection**	**Project Selection FY**	**Number of Projects**	**Funding Amount ($ Million)[10]**
SHARKS	4/09/2020	FY 2020	11/24/2020	FY 2021	11	$35
ULTIMATE	4/21/2020	FY 2020	11/18/2020	FY 2021	17	$16
Solicitation on Topics Informing New Program Areas (Topic L)	5/20/2020	FY 2020	10/06/2020	FY 2021	3	$5.7
Solicitation on Topics Informing New Program Areas (Topic M)	5/20/2020	FY 2020	10/14/2020	FY 2021	5	$4
Solicitation on Topics Informing New Program Areas (Topic N)	5/20/2020	FY 2020	10/14/2020	FY 2021	5	$5
Solicitation on Topics Informing New Program Areas (Topic O)	5/20/2020	FY 2020	10/20/2020	FY 2021	3	$2
Solicitation on Topics Informing New Program Areas (Topic P)	5/20/2020	FY 2020	10/20/2020	FY 2021	3	$2
ECOSynBio	9/10/2020	FY 2020	5/14/2021	FY 2021	15	$25
Solicitation on Topics Informing New Program Areas (Topic Q)	9/17/2020	FY 2020	2/25/2021	FY 2021	6	$10
Solicitation on Topics Informing New Program Areas (Topic R)	9/23/2020	FY 2020	3/4/2021	FY 2021	4	$4.5
Total					**242**	**$403.5**

Summary and Details of FY 2020 Project Selections

In FY 2020, project selections were announced for 170 projects across 14 programs.[13] The details of the focused programs with project selections announced in FY 2020 are:[14]

On November 19, 2019, ARPA-E announced 23 projects were selected to receive $15 million for **DIFFERENTIATE** (Design Intelligence Fostering Formidable Energy Reduction and Enabling Novel Totally Impactful Advanced Technology Enhancements).

Example DIFFERENTIATE Project: Carnegie Mellon University – "High-fidelity Accelerated Design of High-performance Electrochemical Systems" – Pittsburgh, PA ($600,152).

Carnegie Mellon University (CMU) and team will develop an integrated machine learning-accelerated design and optimization workflow that will reduce the time and cost required to develop functional energy materials in devices. The core innovation pairs machine-learning based filtering of candidate materials with accelerated high-fidelity modeling to efficiently search a large design space for high-performance materials under realistic operating conditions. The team will create detailed designs for (1) catalyst systems for electrochemical reactions that convert electrical energy into carbon-neutral chemicals and fuels and (2) electrolyte systems for next-generation batteries. Designing electrochemical systems capable of high turnover and efficiency is a challenge to enable the cost-effective production of carbon-neutral chemicals and fuels. Designing liquid electrolytes for next-generation batteries/fuel cells will provide alternative transportation technologies to petroleum by improving energy density, thus enabling long-range electric vehicles. In particular, the project will develop software- and hardware-accelerated methods using the Julia language for high-fidelity objective function evaluation, and an efficient global optimization approach using sequential learning and design of experiments to achieve its goals.

From January 9, 2020, through September 3, 2020, ARPA-E announced 34 projects were selected to receive $31.7 million for **Solicitation on Topics Informing New Program Areas (Topics G – K)**.

In 2019, ARPA-E announced an ongoing funding opportunity for a range of the most innovative and unconventional ideas across the energy technology spectrum, exploring high-risk R&D that could lead to the development of disruptive technologies. The topics explored under this opportunity are not part of existing ARPA-E programs, but if successful could establish new program areas for ARPA-E to further examine. Thirty-four projects across 5 topics (Topic G, Supporting Entrepreneurial Energy Discoveries; Topic H, Establishing Validation Sites for Field-

[13] This metric includes only projects selected in FY 2020, including GO Competition Challenge 3, DIFFERENTIATE, ESTCP, Solicitation on Topics Informing New Program Areas (Topic G-K), GEMINA, BETHE, FLECCS, ASCEND, REEACH, SCALEUP "Fast Track", SMARTFARM, GAMOW, and REPAIR projects listed in Table 1.

[14] Project counts and funding amounts on pages iv - 13 (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).

Level Emissions Quantification of Agricultural Bioenergy Feedstock Production; Topic I, Electricity System Models for Carbon Capture Resources; Topic J, Biotechnologies to Ensure a Robust Supply of Critical Materials for Clean Energy; and K, Recycle Underutilized Solids to Energy) were selected in FY 2020.

Example Solicitation on Topics Informing New Program Areas (Topic K) Project: Western Research Institute – "Polymer/Oil Co-Processing to Yield Liquid Products" – Laramie, WY ($979,534).

Western Research Institute will explore technologies based on pyrolysis (thermal conversion) and hydrocracking (a chemical process that upgrades low-quality, heavy gas oils) to convert waste, low-value plastic, and paper polymers into high-energy liquid products suitable as fuel, refinery feedstock, or feed for chemicals manufacturing. The pyrolysis technologies involve heating the polymers in oil media to a temperature high enough to break the chemical bonds to produce a liquid product. The pyrolysis may also be applied to low-level conversion of the polymers to yield a slurry feed for a hydrocracker to more efficiently convert the polymers. If successful, the research will open additional avenues for handling and processing portions of municipal solid waste streams.

On February 12, 2020, ARPA-E announced 4 projects were selected to receive $3.4 million for **GO Competition Challenge 1**.

The GO Competition is a series of challenges to develop software management solutions for challenging power grid problems. The competition aims to create a more reliable, resilient, and secure American electricity grid. Future GO Competition challenges are expected to build on the models used in Challenge 1 and may include complicating factors such as solving larger network models, optimizing power flows over both transmission and distribution systems, and stochastic optimization. The GO Competition FOA was announced in FY 2018, with the Challenge 1 awardees selected in FY 2020.

On February 12, 2020, ARPA-E announced 10 projects were selected to receive $3.2 million for **ESTCP** (Enhancing Energy Security Through Defense Partnerships).

In FY 2020, ARPA-E announced a new partnership with DoD's Environmental Security Technology Certification Program (ESTCP) to further demonstrate and validate ARPA-E-derived technologies at DoD installations across the country. ESTCP targets DoD's urgent environmental and installation energy needs to improve Defense readiness, resilience, and costs. Projects under this partnership will conduct demonstrations to validate the performance and operational costs of promising ARPA-E technologies, provide valuable data needed for end-user acceptance, and accelerate the transition of these technologies to commercial use.

Example ESTCP Project: The Mackinac Technology Company – "Mackinac Window Energy Management Systems (WEMS™)" – Rolling Forks, MS ($1,710,110).

The Mackinac WEMS™ technology is a comprehensive system engineered to dramatically improve the insulating properties of single-pane windows. Mackinac WEMS™ units are the only products in the polymer window coverings/attachments sector that not only comply with force protection standards but can also provide enhanced blast protection for building occupants. Two demonstration sites, Fairchild Hall at the U.S. Air Force Academy in Colorado Springs, CO, and the Engineering Building at the Selfridge Air National Guard Base near Mount Clemens, MI, will be used to validate their performance.

On May 13, 2020, ARPA-E announced 12 projects were selected to receive $30.5 million for **PERFORM** (Performance-based Energy Resource Feedback, Optimization, and Risk Management).

PERFORM seeks to develop innovative management systems that represent the relative delivery risk of each asset and balance the collective risk of all assets across the grid. A risk-driven paradigm allows operators to: (i) fully understand the true likelihood of maintaining a supply-demand balance and system reliability, (ii) optimally manage the system, and (iii) assess the true value of essential reliability services. This paradigm shift is critical for all power systems and is essential for grids with high levels of stochastic resources. Projects will propose methods to quantify and manage risk at the asset level and at the system level.

Example PERFORM Project: Georgia Tech Research Corporation – "Risk-Aware Market Clearing for Power Systems (RAMC)" – Atlanta, GA ($3,250,000).

Georgia Tech's Risk-Aware Market Clearing (RAMC) project will provide a blueprint for an end-to-end, data-driven approach where risk is explicitly modeled, quantified, and optimized, striking a tradeoff between cost and system-level risk minimization. The RAMC project focuses on challenges arising from increased stochasticity in generation, load, flow interchanges with adjacent markets, and extreme weather. RAMC addresses these challenges through innovations in machine learning, sampling, and optimization. RAMC quantifies the risk of individual assets from historical data and learns the correlations among assets. It quantifies the system-level risk and learns fast and accurate approximations of multi-stage stochastic optimization algorithms for the day-ahead security-constrained unit commitment, the day-ahead forward reliability assessment commitment, the look-ahead commitment, and the real-time security constrained economic dispatch. RAMC performs real-world, multi-year validations of the proposed approach to balance cost and risk.

On May 13, 2020, ARPA-E announced 9 projects were selected to receive $27 million for **GEMINA** (Generating Electricity Managed by Intelligent Nuclear Assets).

GEMINA teams will develop digital twins and associated technologies for advanced nuclear reactors to strategically design O&M frameworks for the next generation of nuclear power

plants. These teams are designing tools to introduce greater flexibility in reactor systems, increase autonomy in operations, and speed up design iteration, with a goal of reducing costs at advanced reactor power plants. The projects will work to lower O&M costs by using diverse technologies that are driving efficiencies across other industries, such as artificial intelligence (AI), advanced control systems, predictive maintenance, and model-based fault detection. The teams will develop digital twin technologies for robust O&M strategies that can facilitate, among other things, more flexible operations for integration into an electrical grid with a large fraction of intermittent generation resources.

Example GEMINA Project: University of Michigan – "Secure Automation For Advanced Reactor Innovation" – Ann Arbor, MI ($5,195,000).

The University of Michigan will develop physics-based, model-centric, and scalable capabilities to achieve unprecedented integrated state awareness for advanced reactor power plants. Individual modules include (1) a scalable digital twin, (2) a maintenance proactive evaluator to monitor usage and assess the health conditions and maintenance needs of advanced reactors, (3) an operations intelligent controller to achieve autonomous control during normal and accident conditions, and (4) an O&M Deep Supervisor Module to supervise O&M conditions. The team will first validate the product using a molten salt loop operating at the University of Michigan and apply it to the Kairos Power fluoride salt-cooled high temperature reactor design to demonstrate how the proposed capability can be used to optimize plant design.

On April 7, 2020, ARPA-E announced 16 projects were selected to receive $35 million for **BETHE** (Breakthroughs Enabling THermonuclear-fusion Energy).

BETHE projects will work to deliver higher-maturity, lower-cost fusion options via 3 research categories: (1) Concept Development to advance the performance of inherently lower-cost but less-mature fusion concepts; (2) Component Technology Development that could significantly reduce the capital cost of higher-cost, more-mature fusion concepts; and (3) Capability Teams to improve/adapt and apply existing capabilities (including theory/modeling, machine learning, and diagnostics) to accelerate the development of multiple concepts. BETHE projects will address one of these categories. BETHE projects build on ARPA-E's first focused fusion program, Accelerating Low-Cost Plasma Heating and Assembly (ALPHA), to grow the number of privately funded fusion companies. BETHE teams will pursue additional approaches that reduce cost, unit size, and complexity of fusion systems, while smoothing the path to fusion commercialization to include public, private, and philanthropic partnerships with the BETHE teams.

Example BETHE Project: University of Wisconsin-Madison – "An HTS Axisymmetric Magnetic Mirror on a Faster Path to Lower Cost Fusion Energy" – Madison, WI ($5,000,000).

The Wisconsin High-field Axisymmetric Mirror (WHAM) project at the University of Wisconsin-Madison will leverage advances in the stability and confinement of the mirror fusion concept, innovative plasma heating, and high-field superconducting magnets to demonstrate a

potentially transformative development path toward a low-cost linear fusion device. The project aims to demonstrate a novel "end cell" that confines stable, heated plasmas with electron temperatures exceeding 1 keV and a fusion triple product exceeding 1018 keV s/m3. Success in this project would justify follow-on pursuit of the low-cost Break-Even Axisymmetric Tandem (BEAT) device, which would use two of the end cells at either end of a longer central mirror cell to reach breakeven conditions.

On July 13, 2020, ARPA-E announced 12 projects were selected to receive $11.5 million for **FLECCS** (FLExible Carbon Capture and Storage).

FLECCS project teams will work to develop carbon capture and storage (CCS) processes that better enable technologies, such as natural gas power generators, to respond to grid conditions in a high variable renewable energy (VRE) penetration environment. FLECCS project teams are developing CCS retrofits to existing power generators as well as greenfield systems that intake fossil carbon-containing fuel like natural gas or bio-gas and output electricity. The FLECCS program contains two phases, the first of which was selected in FY 2020. FLECCS Phase 1 teams will design, model, and optimize CCS processes that enable flexibility on a high-VRE grid. Later in the program, teams that move to Phase 2 will focus on building components, unit operations, and prototype systems to reduce technical risks and costs. In FLECCS Phase 2, up to $31 million in additional funding will be available for teams. At the conclusion of the Phase 1 period, teams will be downselected based on an engineering design review and the projected economic impact of their Phase 1 projects on a future electricity grid. Selected teams will move on to receive additional funding, further develop their technologies and address Phase 2 challenges.

Example FLECCS Project: Linde Gas North America – "Process Integration and Optimization of an NGCC Power Plant with CO_2 Capture, Hydrogen Production and Storage" – Murray Hill, NJ ($479,966).

Linde Gas aims to develop such a system for natural gas-fired power plants using post-combustion carbon capture and hydrogen technologies. Integrating an electrolyzer for hydrogen production and tanks for hydrogen storage with a natural gas power plant that has carbon capture will enable the plant to operate under more steady-state conditions, improve its efficiency, and increase its capital utilization. Eliminating frequent starts and stops of these large power systems will also reduce fugitive carbon emissions during ramp-ups and ramp-downs. The value of this process design becomes greater as the differential in high and low prices of electricity increases and value for CO_2 emissions improves.

On August 6, 2020, ARPA-E announced 10 projects were selected to receive $33 million for **REPAIR** (Rapid Encapsulation of Pipelines Avoiding Intensive Replacement).

REPAIR teams will develop natural gas transmission pipeline retrofitting technology to rehabilitate existing cast iron and bare steel pipes by creating new, robust pipes inside of old ones. The selected REPAIR teams are developing smart coatings, robotic systems to line the inside of pipes, inspection tools to verify the integrity of the pipes, and mapping tools to enable

3D renderings of pipes and adjacent underground infrastructure. Technologies developed through these projects are working to extend the life of rehabilitated pipes by a minimum of 50 years and ensure they have sufficient material properties to operate without reliance on the exterior pipe, all while meeting utility and regulatory requirements for use in natural gas distribution pipes.

Example REPAIR Project: University of Colorado Boulder – "Testing and Analysis of Pipeline Encapsulation Technologies" – Boulder, CO ($5,400,000).

The University of Colorado Boulder will lead a multi-institutional team to develop a data-driven framework of physical testing and modeling to enable the gas industry to better evaluate products to rehabilitate cast iron and steel natural gas pipes and enhance their performance and longevity. The objective is to validate a 50-year design life for innovative pipe-in-pipe (PIP) systems by developing numerical, analytical, and physical testing protocols. Attributes of each approach are merged to deliver a comprehensive framework for PIP technologies composed of a variety of materials and deposition methods. University of Colorado Boulder's framework characterizes failure modes and establishes performance criteria for pipe replacement technologies to support recommendations for PIP material properties suitable for acceptable design-life performance.

On September 2, 2020, ARPA-E announced 14 projects were selected to receive $29 million for **GAMOW** (Galvanizing Advances in Market-Aligned Fusion for an Overabundance of Watts).

GAMOW is jointly sponsored by ARPA-E and the Office of Science–Fusion Energy Sciences. GAMOW teams will work to close multiple fusion-specific technological gaps to connect a net-energy-gain "fusion core," once it is ready, to a deployable, commercially attractive fusion system. Projects will address one or more R&D categories, including (1) technologies, materials, and superconducting-magnet and fuel-cycle subsystems between the fusion plasma and balance of plant, (2) cost-effective, high-efficiency, high-duty-cycle, and electrical-driver technologies, and (3) cross-cutting areas such as novel fusion materials and advanced and additive manufacturing for fusion-relevant materials, components, and their cost-effective scale-up.

Example GAMOW Project: University of Houston – "Advanced HTS Conductors Customized for Fusion" – Houston, TX ($1,500,000).

RE-Ba-Cu-O (REBCO or rare-earth barium copper oxide) tapes enable >20-T (tesla) magnets in compact, high-field magnetic-fusion devices. Commercial REBCO tapes are expensive and use substrates that limit their yield strength at the operating condition of high-temperature superconductor (HTS) magnets for compact fusion energy systems, however. The University of Houston proposes to address these challenges by developing HTS conductors with increased critical current at >20 T and lower raw-materials cost for use in commercial fusion systems. The team will employ an advanced metal organic chemical vapor deposition process to reduce costs while achieving high critical-current thresholds and use high-strength alloys to increase the

yield strength of REBCO tapes. These innovations could reduce the cost of HTS conductors by a factor of 30.

On August 8, 2020, ARPA-E announced 9 projects were selected to receive $14.5 million for **ASCEND** (Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives).

ASCEND projects work to develop innovative, lightweight, and ultra-efficient all-electric powertrain with advanced thermal management systems that help enable efficient net-zero carbon emissions for single-aisle passenger commercial aircraft. Estimates comparing passenger-distance-specific CO_2 emissions place commercial air travel on single-aisle aircraft at nearly double that of any other individual widely used transportation source, including by rail, bus, or car. ASCEND teams seek to decrease these emissions as well as the economic burden associated with air travel for commercial airlines by developing elements of ultra-high efficient aircraft propulsion systems to use carbon neutral liquid fuels.

Example ASCEND Project: Texas A&M Engineering Experiment Station – "Multi-Physical Co-Design of Next Generation Axial Motors for Aerospace Applications" – College Station, TX ($1,300,000).

Texas A&M will focus on the design, fabrication, and testing of a lightweight and ultra-efficient electric powertrain for aircraft propulsion to reduce the energy costs and emissions of aviation. The team's technology will reach peak power density and efficiency via (1) an axial flux motor with lightweight carbon fiber reinforced structural material, (2) a gallium nitride multilevel inverter, (3) a thermally conductive nanocomposite electrical insulation, and (4) a two-phase thermal management system with zeolite thermal energy storage to absorb the excess heat generated during takeoff. Each subsystem is designed for tight integration with the other subsystems to minimize weight.

On August 8, 2020, ARPA-E announced 9 projects were selected to receive $20 million for **REEACH** (Range Extenders for Electric Aviation with Low Carbon and High Efficiency).

REEACH projects seek to create innovative, cost-effective, and high-performance energy storage and power generation sub-systems for electric aircraft, with a focus on fuel-to-electric power conversion technologies. REEACH and ASCEND work to decrease energy usage and associated carbon emissions for commercial aircraft propulsion systems. Estimates comparing passenger-distance-specific CO_2 emissions place commercial air travel on single-aisle aircraft at nearly double that of any other individual widely used transportation source, including rail, bus, or car. REEACH teams seek to decrease these emissions as well as the economic burden associated with air travel for commercial airlines by developing elements of ultra-high efficient aircraft propulsion systems to use carbon neutral liquid fuels.

Example REEACH Project: Fuceltech Inc. – "Extremely Lightweight Fuel Cell Based Power Supply System for Commercial Aircrafts" – Princeton Junction, NJ ($1,656,438).

Fuceltech proposes to develop an innovative low-cost, lightweight Energy Storage and Power Generation (ESPG) system for commercial aircraft. Fuceltech will develop a monopolar wound fuel cell potentially as high as 10kW rating and a novel stacking approach to deliver hundreds of kWs of power from a single small and lightweight stack. Fuceltech will use ethanol as a fuel and a reformer that delivers extremely low carbon monoxide concentration in the reformate to the fuel cell.

On September 9, 2020, ARPA-E announced 6 projects were selected to receive $16.5 million for **SMARTFARM** (Systems for Monitoring and Analytics for Renewable Transportation Fuels from Agricultural Resources and Management).

SMARTFARM projects will develop technologies that bridge the data gap in the biofuel supply chain by quantifying feedstock-related GHG emissions and soil carbon dynamics at the field level. These technologies will allow for improved efficiency in feedstock production and enable new ag-sector carbon removal and management opportunities. SMARTFARM teams will work to design and develop systems to quantify feedstock production life cycle GHG emissions at the field level reliably, accurately, and cost-effectively. Selected projects are capable of delivering a positive return on investment when field-level carbon emissions reductions are connected to associated biofuel carbon markets. The program also focuses on potential economic benefits to feedstock producers and future carbon management markets, potentially complementing yield-based revenues with incentives for input efficiency and restorative practices. This focus will also help to lay the groundwork for market structures to shift away from national averages and toward lower uncertainty field-based estimates for incentivizing efficiency and other services.

Example SMARTFARM Project: University of Utah – "Soil Organic Carbon Networked Measurement System (SOCNET)" – Salt Lake City, UT ($1,899,317).

The inability to measure on-the-spot underground carbon flux and storage within an economically sensible operation cost limits the accurate quantification of carbon sequestration, capture, loss, and storage necessary to achieve a carbon negative bioeconomy and biofuel supply chain. The University of Utah aims to develop and deploy a distributed carbon sensor system that is buried into the soil, capable of locally stimulating a surrounding volume of soils at multiple depths, and sensing carbon and carbon flux at ultra-low operational cost. The sensor will enable high-accuracy and real-time decision data for cost-effective carbon removal, storage, and management.

On September 16, 2020, ARPA-E announced 2 projects were selected to receive $24 million for **SCALEUP Fast-Track** (Seeding Critical Advances for Leading Energy technologies with Untapped Potential).

SCALEUP is a first-of-its-kind initiative that builds on ARPA-E's primary R&D focus, supporting the scaling of high-risk and potentially disruptive new technologies across the full spectrum of energy applications. The program works to take promising energy technologies to the pre-pilot stage of the path to market and ultimately lead to realized commercial impact. SCALEUP "Fast-Track" teams applied under the initial solicitation but were given the opportunity to justify the urgency of their funding need to receive funding at an accelerated pace relative to the full program timeline. ARPA-E developed the "Fast-Track" in response to disruptions in the investor and R&D financing communities caused by COVID-19, as well as related capital concerns on the part of a number of SCALEUP applicants. Teams not selected for the "Fast-Track" option are still eligible and under consideration for funding under the full SCALEUP program, where selections occurred in January 2021.

Example SCALEUP Fast-Track Project: Natron Energy – "Domestic Manufacturing of Sodium-Ion Batteries" – Santa Clara, CA ($19,883,951).

The project aims to scale up production of Natron Energy's (Natron) Prussian blue electrode sodium-ion batteries by 30x to 18,000 trays per year, and fully de-risk the resulting supply chain and products through continuous production and sales for 6 months. The primary product is an 8-kilowatt, 50-volt battery tray for use in data centers to manage peak compute load and provide critical backup power. Natron's tray provides data center operators up to 2x higher power density and 10x longer cycle life than existing products, along with superior safety performance. To build the supply chain, Natron and its partners will adapt industry-standard chemicals synthesis and battery manufacturing equipment and processes to produce Natron's cells and battery systems for data center applications. The project will also position Natron's Prussian blue electrode sodium-ion batteries for emerging applications, such as electric vehicle fast charging and dispatchable storage for grid power.

Summary of FY 2021 Project Selections for FOAs Announced in FY 2020

In FY 2020 ARPA-E issued solicitations for four programs with 72 project selections announced in FY 2021:

From October 6, 2020, through March 4, 2021, ARPA-E announced that 29 projects were selected to receive $33.2 million for **Solicitation on Topics Informing New Program Areas (Topics L – R)**.

Seven topics (Topic L, Insulating Nanofluids and Solids to Upgrade our Large Aging Transformer Equipment; Topic M, Mining Incinerated Disposal Ash Streams; Topic N, Waste into X; Topic O, Direct Removal of Carbon Dioxide from Oceanwater; Topic P, Direct Removal of Carbon Dioxide from Ambient Air; Topic Q, Connecting Aviation by Lighter Electric Systems; and Topic R, LOwering CO_2: Models to Optimize Train Infrastructure, Vehicles, and Energy Storage) were announced in FY 2020 with selections occurring in FY 2021.

On November 18, 2020, ARPA-E announced 17 projects were selected to receive $16 million for **ULTIMATE** *(Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency)*.

ULTIMATE Phase I teams will demonstrate proof of concept for alloy compositions, coatings, and manufacturing processes through modeling and laboratory scale tensile coupon testing of basic properties. At the conclusion of Phase 1, teams will be down selected based on technical review to receive additional funding for development of selected alloy compositions and coatings, as well as the production of generic small-scale turbine blades to demonstrate manufacturability of designs. In ULTIMATE Phase 2, up to $14 million in additional funds will be available to teams.

On November 24, 2020, ARPA-E announced 11 projects were selected to receive $35 million for **SHARKS** *(Submarine Hydrokinetic And Riverine Kilo-megawatt Systems)*.

SHARKS seeks to develop new technical pathways to design economically competitive Hydrokinetic Turbines (HKT) for tidal and riverine currents. These renewable energy resources are highly reliable, forecastable, and typically co-located with demand centers. HKTs are suited for both micro-grids that supply energy to remote communities without grid connections and utility-scale grid-connected applications. This program seeks to fund new holistic HKT designs to reduce significantly their levelized cost of energy (LCOE). SHARKS encourages the application of control co-design (CCD), co-design (CD), and designing for operation and maintenance (DFO) methodologies.

On May 14, 2021, ARPA-E announced that 15 projects were selected to receive up to $25 million for **ECOSynBio** (Energy and Carbon Optimized Synthesis for the Bioeconomy).

The ECOSynBio program aims to promote the use of advanced synthetic biology tools to engineer novel biomass conversion platforms and systems. These systems will be designed to use external energy inputs to substantially increase carbon use, versatility, and efficiency while achieving economies of scale for industrial applications. Successful platforms will offer new capacities for the bioeconomy by enabling fully carbon-optimized renewable fuel and chemical synthesis with maximum carbon and resource efficiency.

Table 2 below summarizes ARPA-E's programs to date. A full list of the projects selected during FY 2020 can be found in Appendix I. Additional information related to these projects is on ARPA-E's website: http://arpa-e.energy.gov.

Funding Year	PROGRAM NAME	NUMBER OF PROJECTS	FUNDING AMOUNT ($ Million) [15]
	OPEN 2009	41	$174
	Batteries for Electrical Energy Storage in Transportation (BEEST)	12	$38
	Innovative Materials and Processes for Advanced Carbon Capture Technologies (IMPACCT)	15	$40
	Electrofuels	13	$48
	Agile Delivery of Electrical Power Technology (ADEPT)	14	$38
	Building Energy Efficiency Through Innovative Thermodevices (BEETIT)	17	$38
	Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)	15	$40
	Plants Engineered To Replace Oil (PETRO)	10	$56
	High Energy Advanced Thermal Storage (HEATS)	15	$37
	Rare Earth Alternatives in Critical Technologies (REACT)	14	$39
	Green Electricity Network Integration (GENI)	15	$43
	Solar Agile Delivery of Electrical Power Technology (Solar ADEPT)	7	$12
	Methane Opportunities for Vehicular Energy (MOVE)	13	$42
	Advanced Management and Protection of Energy Storage Devices (AMPED)	15	$34
	OPEN 2012	66	$171
	Innovative Development in Energy-related Applied Science (IDEAS)	59	$28
	Robust Affordable Next Generation Energy Storage Systems (RANGE)	22	$45
	Reducing Emissions using Methanotrophic Organisms for Transportation Energy (REMOTE)	16	$48
	Modern Electro/Thermochemical Advancements for Light metals Systems (METALS)	19	$45
	Full-Spectrum Optimized Conversion and Utilization of Sunlight (FOCUS)	14	$35
	Strategies for Wide Bandgap, Inexpensive Transistors for Controlling High Efficiency Systems (SWITCHES) & SBIR/STTR	14	$36
	Reliable Electricity Based on Electrochemical Systems (REBELS)	13	$37

[15] All 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.

	Cycling Hardware to Analyze and Ready Grid-Scale Electricity Storage (CHARGES)	2	$6.5
	Delivering Efficient Local Thermal Amenities (DELTA)	11	$32
	Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR)	12	$39
	Accelerating Low-cost Plasma Heating and Assembly (ALPHA)	9	$31
	Advanced Research In Dry cooling (ARID)	15	$33
	GENerators for Small Electrical and Thermal Systems (GENSETS)	14	$37
	Transportation Energy Resources from Renewable Agriculture (TERRA)	6	$38
	Traveler Response Architecture using Novel Signaling for Network Efficiency in Transportation (TRANSNET)	5	$15
	Micro-scale Optimized Solar-cell Arrays with Integrated Concentration (MOSAIC)	11	$26
	OPEN 2015	39	$124
	Network Optimized Distributed Energy Systems (NODES)	12	$35
	Generating Realistic Information for the Development of Distribution and Transmission Algorithms (GRID DATA)	7	$11
	Single-Pane Highly Insulating Efficient Lucid Design (SHIELD)	14	$27
	Integration and Optimization of Novel Ion-Conducting Solids (IONICS)	16	$37
	Next-Generation Energy Technologies for Connected and Automated On-Road Vehicles (NEXTCAR)	11	$35
	Rhizosphere Observations Optimizing Terrestrial Sequestration (ROOTS)	10	$36
	Renewable Energy to Fuels Through Utilization of Energy-Dense Liquids (REFUEL)	16	$33
	Energy-Efficient Light-Wave Integrated Technology Enabling Networks that Enhance Datacenters (ENLITENED)	9	$25
	Power Nitride Doping Innovation Offers Devices Enabling SWITCHES (PNDIODES)	7	$6.9
	Creating Innovative and Reliable Circuits Using Inventive Topologies and Semiconductors (CIRCUITS)	21	$30
	Macroalgae Research Inspiring Novel Energy Resources (MARINER)	18	$22
	Saving Energy Nationwide in Structures with Occupancy Recognition (SENSOR)	15	$20
	Innovative Natural-gas Technologies for Efficiency Gain in Reliable and Affordable Thermochemical Electricity-generation (INTEGRATE)	8	$16
	Modeling-Enhanced Innovations Trailblazing Nuclear Energy Reinvigoration (MEITNER)	6	$14
	Duration Addition to electricity Storage (DAYS)	10	$28
	Building Reliable Electronics to Achieve Kilovolt Effective Ratings Safely (BREAKERS)	8	$21
	High Intensity Thermal Exchange through Materials and Manufacturing Processes (HITEMMP)	15	$29.2
	OPEN 2018 (and related OPEN+ cohorts)	77	$202.8

	Aerodynamic Turbines Lighter and Afloat with Nautical Technologies and Integrated Servo-control (ATLANTIS)	13	$26
	Solicitation on Topics Informing New Program Areas (Topics A – F)	33	$38
FY 2019 FOA / FY 2020 SECLECTION	Grid Optimization (GO) Competition Challenge 1 16	10	$3.4
	Design Intelligence Fostering Formidable Energy Reduction and Enabling Novel Totally Impactful Advanced Technology Enhancements (DIFFERENTIATE)	23	$15
	Environmental Security Technology Certification Program (ESTCP)	4	$3.2
	Solicitation on Topics Informing New Program Area (Topics G – H)	22	$21.3
	Performance-based Energy Resource Feedback, Optimization, and Risk Management (PERFORM)	12	$30.5
FY 2020	Generating Electricity Managed by Intelligent Nuclear Assets (GEMINA)	9	$27
	Breakthroughs Enabling Thermonuclear-fusion Energy (BETHE)	16	$35
	FLExible Carbon Capture and Storage (FLECCS) 17	12	$11.5
	Solicitation on Topics Informing New Project Areas (Topics I – K)	12	$10.4
	Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives (ASCEND)	9	$14.5
	Range Extenders for Electric Aviation with Low Carbon and High Efficiency (REEACH)	9	$20
	SCALEUP 18	2	$24
	Systems for Monitoring and Analytics for Renewable Transportation Fuels from Agricultural Resources and Management (SMARTFARM)	6	$16.5
	Galvanizing Advances in Market-Aligned Fusion for an Overabundance of Watts (GAMOW)	6	$16.5
	Rapid Encapsulation of Pipelines Avoiding Intensive Replacement (REPAIR)	10	$33
FY 2020 FOA / FY 2021 SELECTION	Solicitation on Topics Informing New Project Areas (Topics L – R)	29	$33.2
	Submarine Hydrokinetic and Riverine Kilo-megawatt Systems (SHARKS)	11	$35
	Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency (ULTIMATE)	17	$16
	Energy and Carbon Optimized Synthesis for the Bioeconomy (ECOSynBio)	15	$25
	TOTAL	1,123	$2,589.5

[16] FOA announced in FY 2018 with projects selected in FY 2020.

[17] Selections for Phase 1 only.

[18] Selections for SCALEUP Fast-Track only. Selections for the SCALEUP FOA, under which the SCALEUP Fast-Track selections fall, occurred in FY 2021.

IV. ARPA-E Energy Innovation Summit

ARPA-E did not hold its annual Energy Innovation Summit in FY 2020. This decision was made in late 2018. In light of COVID-19-related shutdowns, many of which began the week the Summit would have been held, it is likely the decision avoided logistical and financial challenges.

The 2021 ARPA-E Energy Innovation Summit was held virtually on May 24-27, 2021.

V. Conclusion

In FY 2020, ARPA-E announced project selections for **14** focused programs. The programs created through these solicitations cover a wide range of technical areas:[19]

1. DIFFERENATIATE: accelerating the incorporation of machine learning and artificial intelligence into the energy technology and product design processes.
2. ESTCP: partnering with the Department of Defense to further demonstrate and validate ARPA-E-derived technologies at DoD installations across the country.
3. PERFORM: developing innovative management systems that represent the relative delivery risk of each asset, like wind farms or power plants, and balance the collective risk of all assets across the grid.
4. Solicitation on Topics Informing New Program Areas[20]: exploring new areas of technology.
5. GEMINA: developing digital twin technology to reduce O&M costs in the next generation of nuclear power plants.
6. BETHE: developing of timely, commercially viable fusion energy.
7. GAMOW: closing multiple fusion-specific technological gaps that will be needed to connect a net-energy-gain "fusion core" to a deployable, commercially attractive fusion system.
8. ASCEND: developing innovative, lightweight, and ultra-efficient all-electric powertrain with advanced thermal management systems that help enable efficient net-zero carbon emissions for single-aisle passenger commercial aircraft.
9. REEACH: creating innovative, cost-effective, and high-performance energy storage and power generation sub-systems for electric aircraft, with a focus on fuel-to-electric power conversion technologies.

[19] The GO Competition Challenge 1 FOA was released in FY 2018 and selected in FY 2020. The DIFFERENTIATE, ESTCP, PERFORM, and Solicitation on Topics Informing New Project Areas (Topics G and H) FOAs were released in FY 2019, with project selections announced in FY 2020. The GEMINA, BETHE, ASCEND, REEACH, SMARTFARM, GAMOW, REPAIR, SCALEUP Fast-Track, FLECCS, and Solicitation on Topics Informing New Project Areas (Topics I – K) FOAs were released in FY 2020, with project selections also in FY 2020.

[20] In 2019, ARPA-E announced an ongoing funding opportunity exploring R&D technology areas in the energy technology spectrum that could lead to the development of new ARPA-E program spaces. Thirty-four projects across 5 topics (Topic G, Supporting Entrepreneurial Energy Discoveries; Topic H, Establishing Validation Sites for Field-Level Emissions Quantification of Agricultural Bioenergy Feedstock Production; Topic I, Electricity System Models for Carbon Capture Resources; Topic J, Biotechnologies to Ensure a Robust Supply of Critical Materials for Clean Energy; and Topic K, Recycle Underutilized Solids to Energy) were selected in FY 2020.

10. SMARTFARM: developing technologies that bridge the data gap in the biofuel supply chain by quantifying feedstock-related GHG emissions and soil carbon dynamics at the field-level.
11. REPAIR: developing natural gas transmission pipeline retrofitting technology to rehabilitate existing cast iron and bare steel pipes by creating new, robust pipes inside of old ones.
12. GO Competition Challenge 1[21]: developing transformational and disruptive methods for solving the nation's most pressing power system problems.
13. FLECCS: developing CCS processes that better enable technologies, such as natural gas power generators, to be responsive to grid conditions in a high-VRE penetration environment.
14. SCALEUP "Fast-Track": taking promising energy technologies to the pre-pilot stage of the path to market and ultimately lead to realized commercial impact.

In FY 2020, ARPA-E announced FOAs for 13 focused programs. The programs created through these solicitations cover a wide range of technical areas:

1. Solicitation on Topics Informing New Program Areas[22]: exploring new areas of technology.
2. GEMINA: developing digital twin technology to reduce O&M costs in the next generation of nuclear power plants.
3. BETHE: developing of timely, commercially viable fusion energy.
4. GAMOW: closing multiple fusion-specific technological gaps that will be needed to connect a net-energy-gain "fusion core" to a deployable, commercially attractive fusion system.
5. ASCEND: developing innovative, lightweight, and ultra-efficient all-electric powertrain with advanced thermal management systems that help enable efficient net-zero carbon emissions for single-aisle passenger commercial aircraft.
6. REEACH: creating innovative, cost-effective, and high-performance energy storage and power generation sub-systems for electric aircraft, with a focus on fuel-to-electric power conversion technologies.
7. SMARTFARM: developing technologies that bridge the data gap in the biofuel supply chain by quantifying feedstock-related GHG emissions and soil carbon dynamics at the field-level.
8. REPAIR: developing natural gas transmission pipeline retrofitting technology to rehabilitate existing cast iron and bare steel pipes by creating new, robust pipes inside of old ones.

[21] The GO Competition is a series of challenges to develop software management solutions for challenging power grid problems.

[22] In 2019, ARPA-E announced an ongoing funding opportunity exploring R&D technology areas in the energy technology spectrum that could lead to the development of new ARPA-E program spaces. Topics I – R were announced in FY 2020.

9. FLECCS: developing CCS processes that better enable technologies, such as natural gas power generators, to be responsive to grid conditions in a high VRE penetration environment.
10. SCALEUP Fast Track: taking promising energy technologies to the pre-pilot stage of the path to market, ultimately leading to realized commercial impact.
11. ECOSynBio: promoting the use of advanced synthetic biology tools to engineer novel biomass conversion platforms and systems.
12. ULTIMATE: developing ultrahigh temperature materials for gas turbine use in the aviation and power generation industries.
13. SHARKS: developing new economically competitive Hydrokinetic Turbines designs for tidal and riverine currents.

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 energy-related emissions and improve energy efficiency across all sectors of the U.S. economy and maintain the United States' technological lead in the development and deployment of advanced energy technologies.

In FY 2020, ARPA-E program directors provided awardees with technical guidance and developed new programs by engaging diverse communities to identify gaps where ARPA-E funding 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 2020

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
GO Competition Challenge 1	Lawrence Livermore National Laboratory	--	Livermore, CA	$400,000
GO Competition Challenge 1	University of Colorado – Boulder	--	Boulder, CO	$400,000
GO Competition Challenge 1	Georgia Institute of Technology	--	Atlanta, GA	$400,000
GO Competition Challenge 1	Northwestern University	--	Evanston, IL	$400,000

GO Competition Challenge 1	Mississippi State University	--	Mississippi State, MS	$300,000
GO Competition Challenge 1	Nathan Lemons, Hassan Lionel Hijazi	--	Santa Fe, NM	$400,000
GO Competition Challenge 1	Global Optimal Technology, Inc.	--	Ithaca, NY	$200,000
GO Competition Challenge 1	Lehigh University	--	Bethlehem, PA	$400,000
GO Competition Challenge 1	Pearl Street Technologies	--	Pittsburg, PA	$400,000
GO Competition Challenge 1	Pennsylvania State University	--	University Park, PA	$100,000
DIFFERENTIATE	National Renewable Energy Laboratory	End-to-End Optimization for Battery Materials and Molecules by Combining Graph Neural Networks and Reinforcement Learning	Golden, CO	$538,618
DIFFERENTIATE	National Renewable Energy Laboratory	INTEGRATE – Inverse Network Transformations for Efficient Generation of Robust Airfoil and Turbine Enhancements	Golden, CO	$507,878
DIFFERENTIATE	Northwestern University	Adaptive Discovery and Mixed-Variable Optimization of Next Generation Synthesizable Microelectronic Materials	Evanston, IL	$570,712
DIFFERENTIATE	Iowa State University	Context-Aware Learning for Inverse Design in Photovoltaics	Ames, Iowa	$607,138
DIFFERENTIATE	Massachusetts Institute of Technology	Machine Learning Assisted Models for Understanding and Optimizing Boiling Heat Transfer on Scalable Random Surfaces	Cambridge, MA	$521,602
DIFFERENTIATE	Massachusetts Institute of Technology	Global Optimization of Multicomponent Oxide Catalysts for OER/ORR	Cambridge, MA	$1,268,183
DIFFERENTIATE	University of Michigan-Dearborn	ML-ACCEPT: Machine-Learning-enhanced Automated Circuit Configuration and Evaluation of Power Converters	Dearborn, Michigan	$658,321
DIFFERENTIATE	Carnegie Mellon University	Predicting Catalyst Surface Stability under Reaction Conditions Using Deep Reinforcement Learning and Machine Learning Potentials	Pittsburgh, PA	$500,675

DIFFERENTIATE	Julia Computing, Inc.	Accelerating Coupled HVAC-Building Simulation with a Neural Component Architecture	Cambridge, MA	$1,125,679
DIFFERENTIATE	University of Maryland	Invertible Design Manifolds for Heat Transfer Surfaces (INVERT)	College Park, MD	$426,647
DIFFERENTIATE	Los Alamos National Laboratory	Machine Learning based Well Design to Enhance Unconventional Energy Production	Los Alamos, New Mexico	$897,577
DIFFERENTIATE	The University of Texas at Austin	Learning Optimal Aerodynamic Designs	Austin, Texas	$655,410
DIFFERENTIATE	IBM Research	Model-based Reinforcement Learning with Active Learning for Efficient Electrical Power Converter Design	Yorktown Heights, NY	$407,057
DIFFERENTIATE	Carnegie Mellon University	High-fidelity Accelerated Design of High-performance Electrochemical Systems	Pittsburgh, PA	$600,152
DIFFERENTIATE	Stanford University	Energy efficient integrated photonic systems based on inverse design	Stanford, CA	$405,000
DIFFERENTIATE	University of Missouri	Deep Learning Prediction of Protein Complex Structures	Columbia, MO	$167,797
DIFFERENTIATE	United Technologies Research Center	LENS: Learning Enabled Network Synthesis	East Hartford, CT	$697,094
DIFFERENTIATE	United Technologies Research Center	MULTI-LEADER: MULTI-source LEarning-Accelerated Design of high-Efficiency multi-stage compRessor	East Hartford, CT	$564,188
DIFFERENTIATE	GE Research	IMPACT: Design of Integrated Multi-physics Producible Additive Components for Turbomachinery	Niskayuna, NY	$1,365,066
DIFFERENTIATE	GE Research	Pro-ML IDeAS: Probabilistic Machine Learning for Inverse Design of Aerodynamic Systems	Niskayuna, NY	$853,708
DIFFERENTIATE	Princeton University	MLSPICE: Machine Learning based SPICE Modeling Platform for Power Magnetics	Princeton, NJ	$290,383
DIFFERENTIATE	Lawrence Berkeley National Laboratory	Deep Learning and Natural Language Processing for Accelerated Inverse Design of Optical Materials	Berkley, CA	$803,730
DIFFERENTIATE	Pacific Northwest National Laboratory	Machine Learning for Natural Gas to Electric Power System Design	Richland, WA	$401,734

ESTCP	The Mackinac Technology Company	Mackinac Window Energy Management Systems (WEMS™)	Rolling Fork, MS	$1,710,110
ESTCP	SkyCool Systems, Inc.	Reducing Energy and Water Usage by Cooling DoD Facilities with the Sky	Mountain View, CA	$202,811
ESTCP	Switched Source LLC	Increased Distribution System Connectivity through the Application of the Tie Controller	Vestal, NY	$725,850
ESTCP	Case Western Reserve University	Demonstration and validation of a virtual energy audit tool for DoD buildings	Cleveland, OH	$561,524
Solicitation on Topics Informing New Program Areas (Topic G)	Brimstone Energy	Co-Generation of Low-Energy, CO_2-Free Hydrogen and Ordinary Portland Cement from Ca-Rich Basalts	Berkeley, CA	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Sequoia Scientific, Inc.	Real-time, In-situ Sensing of Sediment Properties for Environmental Monitoring of Deep-Sea Polymetallic Nodule Mining	Bellevue, WA	$499,767
Solicitation on Topics Informing New Program Areas (Topic G)	Deep Reach Technology, Inc.	Improved Nodule Collector Design to Mitigate Sediment Plumes	Houston, TX	$497,397
Solicitation on Topics Informing New Program Areas (Topic G)	MOgene Green Chemicals, LLC	Photosynthetic Microorganism-based Consortia to Capture Carbon and Build Soil Organic Matter	St. Louis, MO	$250,000
Solicitation on Topics Informing New Program Areas (Topic G)	HyperJet Fusion Corporation	Plasma Guns for Magnetized Fuel Targets for PJMIF	Chantilly, VA	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Community Energy, Inc.	Chemically Engineered Process for Enhanced Carbon Mineralization Potential	Radnor, PA	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	UHV Technologies, Inc.	Highly Efficient Vacuum Smelting of Aluminum	Lexington, KY	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	HIGHT-TECH	Advanced Catalyst Manufacturing Enabled by Direct Joule Heating	Rockville, MD	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Ultrasonic Technology Solutions	Extremely Fast and Efficient Direct Contact Ultrasonic Drying for Roll To Roll Manufacturing	Knoxville, TN	$500,000

Solicitation on Topics Informing New Program Areas (Topic G)	Otherlab	SeaSTAR: Selective Thalassic Ambulatory Retriever	San Francisco, CA	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Celadyne Technologies, Inc.	Nanoionics Enabled Proton Conducting Ionomers	Austin, TX	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Noon Energy, Inc.	Rechargeable Carbon-oxygen Battery: A New Class of Ultra Low-cost, Lightweight Energy Storage Technology	Palo Alto, CA	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Lectrolyst LLC	Transformation of Carbon Emissions to High-Value Products through a Two-Step Electrochemical Platform	Newark, DE	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Ultra-low Loss Technologies	Space Division Multiplexing with Multi-Core Fiber for Energy Efficient Integrated Photonic Networking Technologies	Santa Barbara, CA	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Phytodetectors, Inc.	Functional Engineering of a Photosynthetic Desalination Pump Circuit	Fort Collins, CO	$249,733
Solicitation on Topics Informing New Program Areas (Topic G)	Verdox, Inc	Electro-swing Adsorption for High Efficiency Direct Air Capture	Winchester, MA	$500,000
Solicitation on Topics Informing New Program Areas (Topic G)	Cambridge Crops, Inc.	Enabling Technology - Reducing Greenhouse Gas Emissions and Energy Demands via Scaling Advanced 3D Culture Bioreactors	Somerville, MA	$500,000
PERFORM	National Renewable Energy Laboratory	An Integrated Paradigm for the Management of Delivery Risk in Electricity Markets: From Batteries to Insurance and Beyond	Golden, CO	$3,408,526
PERFORM	Columbia University	Risk-Aware Power System Control, Dispatch and Market Incentives	New York, New York	$2,061,355
PERFORM	Princeton University	Stochastic Models, Indices & Optimization Algorithms for Pricing & Hedging Reliability Risks in Modern Power Grids	Princeton, NJ	$3,500,000
PERFORM	Energy and Environmental Economics, Inc.	Deploying E3's RESERVE Tool to Enable Advanced Operation of Clean Grids	San Francisco, CA	$595,000

PERFORM	Rensselaer Polytechnic Institute	Risk Segmentation and Portfolio Analysis for Pareto Dominance in High Renewable Penetration and Storage Reserves	Troy, NY	$2,664,000
PERFORM	Lehigh University	Application of Banking Scoring and Rating for Coherent Risk Measures in Electricity Systems	Bethlehem, PA	$2,500,623
PERFORM	Castalune, LLC	Predicting Events to Enable Robust Renewable Grids	Boston, MA	$1,770,760
PERFORM	Tabors Caramanis Rudkevich, Inc.	Stochastic Nodal Adequacy Platform (SNAP)	Newton, MA	$2,000,000
PERFORM	Georgia Institute of Technology	Risk-Aware Market Clearing for Power Systems (RAMC)	Atlanta, GA	$3,250,000
PERFORM	Energy Trading Analytics, LLC	Stochastic Market Auction Redesigned Trading System (SMARTS)	Phoenixville, PA	$3,360,000
PERFORM	Boston University	A New Risk Assessment and Management Paradigm (NewRAMP) in Electricity Markets	Boston, MA	$3,000,000
PERFORM	Duke University	A Grid that's Risk-Aware for Clean Electricity (GRACE)	Durham, NC	$2,437,443
Solicitation on Topics Informing New Program Areas (Topic H)	Oklahoma State University	Establishing Validation Sites for Field-Level Emissions Quantification from Grain Sorghum in Southern Great Plains	Stillwater, OK	$3,100,000
Solicitation on Topics Informing New Program Areas (Topic H)	Craigson Innovation Group, L.L.C.	Novel commercial farm-field network to quantify emissions and carbon storage from agricultural bioenergy feedstock production	Madison, WI	$2,950,000
Solicitation on Topics Informing New Program Areas (Topic H)	University of Illinois	Midwest Bioenergy Crop Landscape Laboratory (MBC-Lab): Capturing Spatio-temporal and Managerial Variations to Provide a Gold Standard Data and Platform for Validating Field-level Emission from Bioenergy Crops	Urbana, IL	$3,300,000
Solicitation on Topics Informing New Program Areas (Topic H)	Arva Intelligence Corp.	Rice n' Grits: Quantifying Environmental Benefits of Bioenergy Crops through Complete Carbon and Nitrogen Accounting	Park City, UT	$2,950,000

Solicitation on Topics Informing New Program Areas (Topic H)	Lawrence Berkeley National Lab	CARBON STANDARD: Carbon Accounting to Redefine Biofeedstock Operation Normality using Sensing Technology Assisted by Numerical and Data Analytics for Reliable Detection	Berkeley, CA	$1,000,000
GEMINA	GE Research	AI-Enabled Predictive Maintenance Digital Twins for Advanced Nuclear Reactors	Niskayuna, NY	$5,412,810
GEMINA	Electric Power Research Institute, Inc.	Build-to-Replace: A New Paradigm for Reducing Advanced Reactor O&M Costs	Palo Alto, CA	$999,464
GEMINA	X-energy, LLC	Advanced Operation & Maintenance Techniques Implemented in the Xe-100 Plant Digital Twin to Reduce Fixed O&M Cost	Rockville, MD	$6,000,000
GEMINA	Argonne National Laboratory	Maintenance of Advanced Reactor Sensors and Components (MARS)	Argonne, IL	$2,200,000
GEMINA	Framatome, Inc.	Digital Twin-Based Asset Performance and Reliability Diagnosis for the HTGR Reactor Cavity Cooling System Using Metroscope	Lynchburg, VA	$809,701
GEMINA	Massachusetts Institute of Technology	High-Fidelity Digital Twins for BWRX-300 Critical Systems	Cambridge, MA	$ 1,787,065
GEMINA	Moltex Energy USA, LLC	SSR APPLIED - Automated Power Plants: Intelligent, Efficient, and Digitized	Wilmington, DE	$3,500,000
GEMINA	University of Michigan	PROJECT "SAFARI"- Secure Automation For Advanced Reactor Innovation	Ann Arbor, MI	$5,195,000
GEMINA	Massachusetts Institute of Technology	Generation of Critical Irradiation Data to Enable Digital Twinning of Molten-Salt Reactors	Cambridge, MA	$899,825
BETHE	University of Wisconsin-Madison	An HTS Axisymmetric Magnetic Mirror on a Faster Path to Lower Cost Fusion Energy	Madison, WI	$5,260,000
BETHE	Zap Energy	Sheared Flow Stabilized Z-Pinch Performance Improvement	Seattle, WA	$1,000,000
BETHE	University of Maryland, Baltimore County	Centrifugal Mirror Fusion Experiment	Baltimore, MD	$4,178,021
BETHE	NK Labs, LLC	Conditions for High-Yield Muon Catalyzed Fusion	Cambridge, MA	$830,000

BETHE	University of Washington	Demonstration of Low-Density, High-Performance Operation of Sustained Spheromaks and Favorable Scalability toward Compact, Low-Cost Fusion Power Plants	Seattle, WA	$1,500,000
BETHE	Los Alamos National Laboratory	Target Formation and Integrated Experiments for Plasma-Jet Driven Magneto-Inertial Fusion	Los Alamos, NM	$4,618,001
BETHE	Commonwealth Fusion Systems	Pulsed High Temperature Superconducting Central Solenoid for Revolutionizing Tokamaks	Cambridge, MA	$2,390,000
BETHE	Princeton Plasma Physics Laboratory	Stellarator Simplification using Permanent Magnets	Princeton, NJ	$3,000,000
BETHE	University of Rochester – Rochester, New York, and Naval Research Laboratory	Advanced Inertial Fusion Energy Target Designs and Driver Development	Washington, DC	$3,500,000
BETHE	Type One Energy Group	Demonstration High Temperature Superconducting Non-Planar Stellarator Magnet with Advanced Manufactured Assemblies	Madison, WI	$630,000
BETHE	Virginia Polytechnic Institute and State University	Capability in Theory, Modeling, and Validation for a Range of Innovative Fusion Concepts Using High-Fidelity Moment-Kinetic Models	Blacksburg, VA	$2,400,000
BETHE	Sapientai, LLC	Data-Enabled Fusion Technology	Austin, Texas	$1,650,000
BETHE	University of Rochester	A Simulation Resource Team for Innovative Fusion Concepts	Rochester, New York	$2,000,000
BETHE	Massachusetts Institute of Technology	Radio Frequency Scenario Modeling for Breakthrough Fusion Concepts	Cambridge, MA	$1,250,000
BETHE	Oak Ridge National Laboratory	Magnetic Field Vector Measurements Using Doppler-Free Saturation Spectroscopy	Oak Ridge, TN	$600,000
BETHE	Los Alamos National Laboratory	Electromagnetic and Particle Diagnostics for Transformative Fusion-Energy Concepts	Los Alamos, NM	$375,000
FLECCS	GE Global Research	Flexible Oxy-Fuel Combustion for High-Penetration Variable Renewables	Niskayuna, NY	$717,658

FLECCS	8 Rivers Capital	Enhancing Responsiveness of Gas Turbine Generators through Retrofitting with Exhaust Gas Recycle and a Phase-Change CO_2 Capture Process	Durham, NC	$1,178,453
FLECCS	Colorado State University	Synergistic Heat Pumped Thermal Storage and Flexible Carbon Capture System	Fort Collins, CO	$1,000,000
FLECCS	RTI International	Advanced CO_2 Capture Solvent Systems for Dynamic Power	Research Triangle Park, NC	$999,470
FLECCS	University of Pittsburgh	Natural Gas/Direct Air Capture Hybrid Plant	Pittsburgh, PA	$800,283
FLECCS	Georgia Institute of Technology	Positive Power with Negative Emissions: Flexible NGCC Enabled by Modular Direct Air Capture	Atlanta, GA	$1,009,210
FLECCS	Linde Gas North America	Process Integration and Optimization of an NGCC Power Plant with CO_2 Capture, Hydrogen Production and Storage	Murray Hill, NJ	$479,966
FLECCS	Massachusetts Institute of Technology	Power Plant CO_2 Capture Integrated with Lime-based Direct Air Capture	Cambridge, MA	$810,000
FLECCS	Susteon Inc.	A Rapid Temperature Swing Adsorption Carbon Capture Technology for Optimal Operation of a Fossil Power Plant	Cary, NC	$789,009
FLECCS	Southwest Research Institute	Oxygen Storage Incorporated into the Allam Oxy-Fuel Power Cycle	San Antonio, TX	$762,953
FLECCS	Luna Innovations, Inc.	Flexible FlueCO_2	Roanoke, VA	$989,660
FLECCS	Envergex, LLC	Flexible Low Temperature CO_2 Capture System, E-CACHYS™	Sturbridge, MA	$1,953,416
Solicitation on Topics Informing New Program Areas (Topic I)	National Renewable Energy Laboratory	Multiscale Electricity Modeling for Evaluating Carbon Capture and Sequestration Technologies (MEME-CCS)	Golden, CO	$715,000

Solicitation on Topics Informing New Program Areas (Topic I)	Princeton University	Electricity System Capacity Expansion and Operational Modeling for Evaluation and Optimization of Flexible Carbon Capture and Sequestration Systems	Princeton, NJ	$685,000
ASCEND	Raytheon Technologies Research Center	Ultra-Light, inTegrated, Reliable, Aviation-class, Co-Optimized Motor & Power converter with Advanced Cooling Technology (ULTRA-COMPACT)	East Hartford, CT	$2,330,137
ASCEND	Marquette University	High Power Density Motor Equipped with Additively Manufactured Windings Integrated with Advanced Cooling and Modular Integrated Power Electronics	Milwaukee, WI	$1,600,000
ASCEND	General Electric Global Research	Electric Flightworthy Lightweight Integrated Thermally-Enhanced powertrain System (eFLITES) for Narrow-body Commercial Aircraft	Niskayuna, NY	$2,300,000
ASCEND	Honeywell	Advanced Electric Propulsion System (AEPS)	Torrance, CA	$1,800,000
ASCEND	University of California, Santa Cruz	Flux-Switching Machine Based All-Electric Power Train for Future Aircraft	Santa Cruz, CA	$854,495
ASCEND	Texas A&M Engineering Experiment Station	Multi-Physical Co-Design of Next Generation Axial Motors for Aerospace Applications	College Station, TX	$1,300,000
ASCEND	Hyper Tech Research Inc.	Cryo Thermal Management of High Power Density Motors and Drives	Columbus, OH	$2,910,479
ASCEND	Wright Electric	2nd Generation Motor for Large Electric Aircraft Propulsion Systems	Albany, NY	$647,039
ASCEND	Advanced Magnet Lab, Inc.	High Power Density Dual Rotor Permanent Magnet Motor with Integrated Cooling and Drive for Aircraft Propulsion	Melbourne, FL	$655,354
REEACH	Raytheon Technologies Research Center	Compact Propulsion Engine Optimized with Waste Heat Recovery (CO-POWER)	East Hartford, CT	$2,815,760
REEACH	Raytheon Technologies Research Center	Zero-carbon Ammonia-Powered Turboelectric (ZAPTurbo) Propulsion System	East Hartford, CT	$2,652,778

REEACH	General Electric Company, GE Research	FueL CelL Embedded ENgine (FLyCLEEN)	Niskayuna, NY	$2,529,340
REEACH	University of Maryland	Hybrid SOFC-Turbogenerator for Aircraft	College Park, MD	$2,798,489
REEACH	University of Louisiana at Lafayette	High Performance Metal-Supported SOFC System for Range Extension of Commercial Aviation	Lafayette, LA	$2,263,000
REEACH	University of California, San Diego	High-Efficiency and Low-Carbon Energy Storage and Power Generation System for Electric Aviation	San Diego, CA	$2,131,246
REEACH	Fuceltech Inc.	Extremely Lightweight Fuel Cell Based Power Supply System for Commercial Aircrafts	Princeton Junction, NJ	$1,656,438
REEACH	Precision Combustion, Inc.	SOFCs for FLIGHT	North Haven, CT	$1,750,590
REEACH	Tennessee Technological University	High Power Density Carbon Neutral Electrical Power Generation for Air Vehicles	Cookeville, TN	$1,437,287
SCALEUP Fast-Track	Natron Energy	Domestic Manufacturing of Sodium-Ion Batteries	Santa Clara, CA	$19,883,951
SCALEUP Fast-Track	Bridger Photonics, Inc.	Scaling Disruptive Methane Leak Detection and Quantification	Bozeman, MT	$4,572,000
GAMOW	Oak Ridge National Laboratory	Fusion Energy Reactor Models Integrator (FERMI)	Oak Ridge, TN	$3,100,000
GAMOW	University of California, San Diego	Renewable Low-Z Wall for Fusion Reactors with Built-In Tritium Recovery	La Jolla, CA	$1,750,000
GAMOW	Savannah River National Laboratory	Process Intensification Scale-Up of Direct LiT Electrolysis	Aiken, SC	$1,500,000
GAMOW	Colorado School of Mines	Interfacial-Engineered Membranes for Efficient Tritium Extraction	Golden, CO	$1,397,973
GAMOW	Savannah River National Laboratory	EM-Enhanced HyPOR Loop for Fast Fusion Fuel Cycles	Aiken, SC	$2,300,000
GAMOW	University of Houston	Advanced HTS Conductors Customized for Fusion	Houston, TX	$1,500,000
GAMOW	Princeton Fusion Systems	Wide-Bandgap Semiconductor Amplifiers for Plasma Heating and Control	Plainsboro, NJ	$1,100,000
GAMOW	University of California, Los Angeles	AMPERE - Advanced Materials for Plasma-Exposed Robust Electrodes	Los Angeles, CA	$1,250,000

GAMOW	Bridge 12 Technologies, Inc.	High Efficiency, Megawatt-Class Gyrotrons for Instability Control of Burning-Plasma Machines	Framingham, MA	$2,300,000
GAMOW	Phoenix, LLC	Application of Plasma-Window Technology to Enable an Ultra-High-Flux DT Neutron Source	Madison, WI	$2,500,000
GAMOW	Oak Ridge National Laboratory	Advance Castable Nanostructured Alloys for First-Wall/Blanket Applications	Oak Ridge, TN	$3,300,000
GAMOW	Stony Brook University	ENHANCED Shield: A Critical Materials Technology Enabling Compact Superconducting Tokamaks	Stony Brook, NY	$2,400,000
GAMOW	Pacific Northwest National Laboratory	Microstructure Optimization and Novel Processing Development of ODS Steels for Fusion Environments	Richland, Washington	$2,250,000
GAMOW	Oak Ridge National Laboratory	Plasma-Facing Component Innovations by Advanced Manufacturing and Design	Oak Ridge, TN	$2,250,000
REPAIR	Oak Ridge National Laboratory	Structural Materials-aided Advanced Renewal Technology for REPAIR (SMART REPAIR)	Oak Ridge, TN	$5,000,000
REPAIR	University of Colorado, Boulder	Testing and Analysis of Pipeline Encapsulation Technologies	Boulder, CO	$5,400,000
REPAIR	General Electric Global Research	PipeLine Underground Trenchless Overhaul (PLUTO)	Niskayuna, NY	$5,000,000
REPAIR	University of Maryland	Pipe-in-Pipe by Rapid, Continuous, Smart Alloy Coating	College Park, MD	$1,000,000
REPAIR	Autonomic Materials	Autonomous Rehabilitation and Maintenance of Natural Gas Pipes	Champaign, IL	$5,000,000
REPAIR	Carnegie Mellon University	Confined Space Mapping Module for In-Pipe Repair Robots	Pittsburgh, PA	$1,200,000
REPAIR	University of Pittsburgh	“Innervated” Pipelines: A New Technology Platform for In-Situ Repair and Embedded Intelligence	Pittsburgh, PA	$1,000,000
REPAIR	University of Delaware Center for Composite Materials	TuFF Internal Wrap for Rapid Pipeline Repair (TuFF iWRAP)	Newark, DE	$5,954,637
REPAIR	White River Technologies	New and Innovative 3D Mapping Technology to Enable Rehabilitation of Natural Gas Pipe Infrastructure	Newton, MA	$2,000,000

REPAIR	ULC Robotics	Cold Spray Additive Manufacturing for New Pipeline Fabrication in Live, Natural Gas Distribution Mains	Hauppauge, NY	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic J)	Michigan Technological University	In-Situ Bioleaching of Manganese by Dissimilatory Reduction	Houghton, MI	$218,916
Solicitation on Topics Informing New Program Areas (Topic J)	University of California Berkeley	Ligand Facilitated Bioaccumulation: Biomining of Rare Earth and Other Critical Metals from Electronic Wastes	Berkeley, CA	$1,100,000
Solicitation on Topics Informing New Program Areas (Topic J)	Pacific Northwest National Laboratory	UNrealized Critical Lanthanide Extraction via Sea Algae Mining (UNCLE-SAM): Domestic production of critical minerals from seawater	Sequim, WA	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic J)	Tufts University	Living Filter Designs for In-line Recovery and Sorting of Critical Materials	Medford, MA	$600,000
Solicitation on Topics Informing New Program Areas (Topic J)	Columbia University	Development of Biological and Electrochemical Technologies for the Clean Extraction of Copper and Critical Materials from Low Grade Ores	New York, NY	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic J)	Cornell University	Engineered Microorganisms for Enhanced Rare Earth Element Bio-Mining and Separations	Ithaca, NY	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic K)	Western Research Institute	Polymer/Oil Co-processing to Yield Liquid Products (MEME-CCS)	Laramie, WY	$979,534
Solicitation on Topics Informing New Program Areas (Topic K)	Argonne National Laboratory	Selective Hydrogenolysis of Pre-Consumer Polyolefins to Premium Synthetic Lubricants	Lemont, IL	$492,571
Solicitation on Topics Informing New Program Areas (Topic K)	Johns Hopkins University	Hydrocracking Plastic Mixtures into Xylene	Baltimore, MD	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic K)	Altex Technologies	Low Cost Feed Flexible Plastics Reuse (LCFFPR)	San Jose, CA	$999,997