U.S. DEPARTMENT OF ENERGY

ARPA-E Fiscal Year 2021 Annual Report

Report to Congress
June 2023

United States Department of Energy
Washington, DC 20585

Message from the Director

The mission of the Department of Energy's (DOE) Advanced Research Projects Agency – Energy (ARPA-E) is to enhance the economic and energy security of the United States (U.S.) through the development of energy technologies and to ensure that the U.S. maintains a technological lead in developing and deploying advanced energy technologies. To fulfill this mission, 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. The agency helps those teams to both develop and strategically prepare to deploy their technologies.

Including both new funding opportunities and project selections, ARPA-E accounted for $390.6 million in early-stage research and development (R&D) funding in fiscal year (FY) 2021.

In FY 2021, ARPA-E announced a total of seven funding opportunities for up to $209 million in early-stage funding. ARPA-E issued four Funding Opportunity Announcements (FOA). Three of these were for R&D programs focused on specific technical areas and the fourth was an OPEN FOA, which is non-technology specific and offers all potential innovators the opportunity to apply for ARPA-E support. Historically, ARPA-E issues an OPEN FOA every three years. The agency also added three Exploratory Topics to its Solicitation on Topics Informing New Program Areas. This multi-topic solicitation is designed to support high-risk R&D leading to the development of potentially disruptive new technologies across the full spectrum of energy applications. Topics under this FOA will explore new areas of technology development that, if successful, could establish new program areas for ARPA-E, or complement the current portfolio of ARPA-E programs.

ARPA-E also selected 109 projects for a total of $205.6 million in funding in FY 2021. Each project ARPA-E selects is managed as part of either a focused program, OPEN program, or Exploratory Topic. Projects are commonly selected in a different fiscal year than their funding opportunity is announced, but not always.

In addition to providing both financial and technical support to high-risk/high-potential energy R&D, ARPA-E also provides commercialization guidance, called technology-to-market. ARPA-E tracks key early indicators that help illustrate how the agency's support drives commercial impact. This impact can include private-sector follow-on funding, new company formation, partnership with other government agencies, publications, inventions, and patents.

Many ARPA-E project teams have continued to advance their technologies toward market impact since the agency's establishment. As of September 2021, 109 new companies have formed by ARPA-E projects, 253 licenses have been reported from ARPA-E projects, 266 projects have partnered with other government agencies for further development, and 183 project teams have attracted more than $7.6 billion in private-sector follow-on funding to

continue to advance the commercialization of their technology[1]. Additionally, ARPA-E has provided financial assistance awards for research and development to 17 companies that have either been acquired, merged, or made initial public offerings (IPO) [2] with market valuations worth $19.4 billion.

ARPA-E projects have also helped advance general scientific understanding and technological innovation through 4,871 peer-reviewed journal articles and 789 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.

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

- **The Honorable Joseph 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 Bernard Sanders**
  Chair, Subcommittee on Energy
  Senate Committee on Energy and Natural Resources

- **The Honorable Josh Hawley**
  Ranking Member, Subcommittee on Energy
  Senate Committee on Energy and Natural Resources

- **The Honorable Cathy McMorris Rodgers**
  Chair, House Committee on Energy and Commerce

- **The Honorable Frank Pallone**
  Ranking Member, House Committee on Energy and Commerce

[1] The 'Follow on Funding' value includes any commercial funding committed or received from other sources (e.g., private investors, venture capital, etc.) after the 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] The total enterprise valuation number for public listing transactions, acquisitions, and company sales is reported separately from the 'follow on funding' number. This 'acquired, merged, and made initial IPO' number includes development capital and equity valuation minus cash on hand.

- **The Honorable Frank Lucas**
  Chairman, House Committee on Science, Space, and Technology

- **The Honorable Zoe Lofgren**
  Ranking Member, House Committee on Science, Space, and Technology

- **The Honorable Brandon Williams**
  Chairman, Subcommittee on Energy
  House Committee on Science, Space, and Technology

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

- **The Honorable Patty Murray**
  Chair, Senate Committee on Appropriations

- **The Honorable Susan Collins**
  Vice Chair, 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 Kay Granger**
  Chairwoman, House Committee on Appropriations

- **The Honorable Rosa DeLauro**
  Ranking Member, House Committee on Appropriations

- **The Honorable Chuck Fleischmann**
  Chairman, Subcommittee on Energy and Water Development and Related Agencies
  House Committee on Appropriations

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

If you have any questions or need additional information, please contact me or Ms. Katie Donley, Director, Office of Budget, Office of the Chief Financial Officer, at (202) 586-0176; Ms. Janie Thompson, Deputy Assistant Secretary for House Affairs or Ms. Rebecca Ward, Deputy Assistant Secretary for Senate Affairs, Office of Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Dr. Evelyn N. Wang
Director
Advanced Research Projects Agency-Energy

Executive Summary

The Advanced Research Projects Agency-Energy (ARPA-E) funds high-risk/high-potential energy innovation research & development (R&D). The agency's mission is to advance energy innovations that will create a more secure, affordable, and sustainable American energy future.

This report presents a summary of ARPA-E's funding activities during fiscal year (FY) 2021 to include both funding opportunity announcements (FOA) and project selections. ARPA-E FOAs are notices of new funding opportunities tied to a specific ARPA-E initiative (e.g., focused program, OPEN program, Exploratory Topic). Energy innovators with relevant ideas are encouraged to apply to the FOA. After a comprehensive and well-defined review process, applicants are selected to perform R&D work under that funding opportunity and a contract including specific technical milestones is negotiated and then awarded.

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 innovators with funding, technical assistance, and market awareness. As an aspect of its due diligence, 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 DOE applied R&D programs.

In FY 2021, ARPA-E announced seven funding opportunities, which covered a broad array of energy technologies:

1. Up to $24.0 million through three Exploratory Topics to explore new areas of technology for **Solicitation on Topics Informing New Program Areas**;[3]

2. Up to $10.0 million to develop a Technology Integration Platform to demonstrate next-generation ammonia production from intermittent renewable energy in a test-bed environment and its use for energy generation through **REFUEL + IT**[4] *(Renewable Energy to Fuels through Utilization of Energy-dense Liquids + Integration and Testing);*

3. Up to $100.0 million to support some of America's top energy innovators' R&D projects as they seek to develop technologies to transform the nation's energy system through the agency's fifth OPEN solicitation, **OPEN 2021**;

[3] In 2019, ARPA-E issued the Solicitation on Topics Informing New Program Areas about an ongoing funding mechanism to explore R&D technology areas that could lead to the development of new ARPA-E program spaces. In FY 2021, ARPA-E announced 3 Exploratory Topics within this solicitation: (1) Topic S – Topology Optimization and Additive Manufacturing for Performance Enhancement of High Temperature and High-Pressure Heat Exchanges; (2) Topic T – Supporting Entrepreneurial Energy Discoveries (SEED); and (3) Topic U – Sulfur Hexaflouride-Free Routes for Electrical Equipment.

[4] The REFUEL FOA was released in FY 2016. The REFUEL + IT FOA was released in FY 2021 to build off the technologies developed in the REFUEL program.

4. Up to $35.0 million to reduce methane emissions from the oil, gas, and coal value chains through **REMEDY** *(Reducing Emissions of Methane Every Day of the Year);* and

5. Up to $40.0 million to enhance the safety, reduce the cost, and increase the efficiency of nuclear power generation through **ONWARDS** *(Optimizing Nuclear Waste and Advanced Reactor Disposal Systems).*

In FY 2021, ARPA-E selected 109 projects across 15 funding opportunities to receive support for early-stage R&D:

1. Four projects were selected to receive $18.0 million through **NEXTCAR Phase II** *(Next-Generation Energy Technologies for Connected and Automated On-Road Vehicles Phase II);*

2. Seven projects were selected to receive $47.0 million through **SCALEUP** *(Seeding Critical Advances for Leading Energy technologies with Untapped Potential);*

3. Eleven projects were selected to receive $35.0 million through **SHARKS** *(Submarine Hydrokinetic And Riverine Kilo-megawatt Systems);*

4. Seventeen projects were selected to receive $16.0 million through **ULTIMATE** *(Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency);*

5. Fifty-four projects were selected to receive $44.6 million through nine Exploratory Topics under the **Solicitations on Topics Informing New Program Areas**[5];

6. Fifteen projects were selected to receive $35.0 million through **ECOSynBio** *(Energy and Carbon Optimized Synthesis for the Bioeconomy);* and

7. One project was selected to receive $10.0 million through **REFUEL + IT**.

In FY 2021, ARPA-E program directors, (1) provided awardees with technical guidance; and (2) engaged diverse communities to identify gaps where ARPA-E funding could lead to new programs to generate, store, and use energy. ARPA-E also continued to provide awardees with

[5] In FY 2021, ARPA-E selected projects for nine Exploratory Topics within this solicitation: (1) Topic L – Insulating Nanofluids and Solids to Upgrade our Large Aging Transformer Equipment; (2) Topic M – Mining Incinerated Disposal Ash Streams; (3) Topic N – Waste into X; (4)Topic O – Direct Removal of Carbon Dioxide from Oceanwater; (5) Topic P – Direct Removal of Carbon Dioxide from Ambient Air; (6) Topic Q – Connecting Aviation by Lighter Electric Systems; (7) Topic R – Lowering CO2: Models to Optimize Train Infrastructure, Vehicles, and Energy Storage; (8) Topic S – Topology Optimization and Additive Manufacturing for Performance Enhancement of High Temperature High-Pressure Heat Exchangers; and (9) Topic T – Supporting Entrepreneurial Energy Discoveries (SEED).

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 2021
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."*

Advanced Research Projects Agency-Energy (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 Department of Energy (DOE) applied research & development (R&D) programs.

II. Fiscal Year 2021 Appropriation

The Further Consolidated Appropriations Act, 2021 included $427 million in fiscal year (FY) 2021 funds for ARPA-E.

III. Funding Opportunity Announcements (FOA)

In FY 2021, ARPA-E announced seven funding opportunities[6] for up to $209 million. 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.

[6] Including Solicitation on Topics Informing New Program Areas (Topics S – U), REFUEL + IT, OPEN 2021, REMEDY, and ONWARDS.

The table below summarizes the funding opportunities announced in FY 2021.

Table 1: Summary of ARPA-E Funding Opportunities in FY 2021

Program	Funding Opportunity Announcement	Funding Opportunity FY	Funding Amount at Time of Announcement ($ Million)[7]	Project Selection	Project Selection FY	Number of Projects	Funding Amount at Time of Project Selection ($ Million)[8]
Solicitation on Topics Informing New Program Areas (Topic S)[9]	10/8/2020	FY 2021	$4.0	3/4/2021	FY 2021	5	$4.0
Solicitation on Topics Informing New Program Areas (Topic T)[10]	11/12/2020	FY 2021	$10.0	3/31/2021	FY 2021	20	$9.6
REFUEL + IT[11]	11/20/2020	FY 2021	$10.0	8/6/2021	FY 2021	1	$10.0
OPEN 2021	2/11/2021	FY 2021	$100.0	2/14/2022	FY 2022	68	$175.0
REMEDY	4/8/2021	FY 2021	$35.0	12/2/2021	FY 2022	12	$35.0
ONWARDS	5/19/2021	FY 2021	$40.0	3/10/2022	FY 2022	11	$36.0
Solicitation on Topics Informing New Program Areas (Topic U)	5/21/2021	FY 2021	$10.0	10/5/2021	FY 2022	4	$9.4

The funding amounts detailed below reflect the potential funding amount at the time of the announcement. The funding amounts may change at the time of the project selection.

Summary of ARPA-E's funding opportunities announced in FY 2021:

From October 8, 2020, to May 21, 2021, ARPA-E announced three Exploratory Topics under the **Solicitation on Topics Informing New Program Areas**. Topic S announced up to $4 million in

[7] Funding levels shown in this column are the amounts at the time of the FOA. The final funding amount may change by the time of project selection.
[8] Funding levels shown in in this column are as of the date of the project selection. The final number of projects and funding amounts are subject to change based on award negotiations and ongoing program management.
[9] This funding opportunity was also included in Table 2 of section IV: Project Selections because the funding opportunity was announced in FY 2021 and the project selections occurred in FY 2021.
[10] This funding opportunity was also included in Table 2 of section IV: Project Selections because the funding opportunity was announced in FY 2021 and the project selections occurred in FY 2021.
[11] This funding opportunity was also included in Table 2 of section IV: Project Selections because the funding opportunity was announced in FY 2021 and the project selections occurred in FY 2021.

funding, Topic T announced up to $10 million in funding, and Topic U announced up to $10 million in funding.

ARPA-E issued the Solicitation on Topics Informing New Program Areas in 2019, as a flexible, simplified, ongoing funding mechanism used as needed for smaller efforts that do not fit the typical focused program model. This flexible opportunity is used to fund exploratory and disruptive R&D seedlings, provide resource teams that support focused programs, and investigate topic areas in which a full focused program may later be developed. This ability to respond to needs in a quick and agile manner enables ARPA-E to better support focused programs while constantly pursuing innovation in new areas.

Topic S focused on Topology Optimization and Additive Manufacturing for Performance Enhancement of High Temperature and High-Pressure Heat Exchangers; Topic T focused on Supporting Entrepreneurial Energy Discoveries (SEED); and Topic U focused on Sulfur Hexaflouride (SF-6)-Free Routes for Electrical Equipment. All three topics were announced in FY 2021.

On November 20, 2020, ARPA-E announced up to $10 million in funding for **REFUEL + IT**[12] (Renewable Energy to Fuels through Utilization of Energy-dense Liquids + Integration and Testing).

In 2016, ARPA-E launched the REFUEL program to develop technologies to convert air and water into Carbon Neutral Liquid Fuels (CNLF). The goal was for CNLF developed under REFUEL to be stored, transported, and later converted into hydrogen or electricity to provide power for transportation applications in the same way as currently used petroleum-based fuels. Over the course of the program, next-generation CNLF technologies were developed utilizing new fuel cell designs, new ammonia conversion and separation processes, and new membranes. As the program continued, ARPA-E began to see that to effectively scale and commercialize these CNLF technologies, there was a need to demonstrate and test them under realistic use-case scenarios.

To address this need, ARPA-E launched a supplemental program – REFUEL + IT – focused on the Integration and Testing (IT) of the type of technologies developed within the REFUEL program. REFUEL + IT seeks to develop a Technology Integration Platform (TIP) to demonstrate next-generation ammonia production from intermittent renewable energy in a test-bed environment and its use for energy generation.

On February 11, 2021, ARPA-E announced up to $100 million in funding for **OPEN 2021.**

[12] The REFUEL FOA was released in FY 2016. The REFUEL + IT FOA was released in FY 2021 to build off the technologies developed in the REFUEL program.

In addition to its focused programs, which are targeted at specific technical areas, ARPA-E issues periodic OPEN programs approximately every three years. ARPA-E uses OPEN programs to identify high-potential projects that address the full range of energy-related technologies, including areas that are outside the current ARPA-E portfolio. The objective of an ARPA-E OPEN program is to support the development of potentially disruptive new technologies across the full spectrum of energy applications.

On April 8, 2021, ARPA-E announced up to $35 million in funding for **REMEDY** (Reducing Emissions of Methane Every Day of the Year).

REMEDY is a three-year, $35 million research program to reduce methane emissions from three sources in the oil, gas, and coal value chains:

1. Exhaust from 50,000 natural gas-fired lean-burn engines. These engines are used to drive compressors, generate electricity, and increasingly repower ships.
2. The estimated 300,000 flares required for safe operation of oil and gas facilities.
3. Coal mine ventilation air methane exhausted from 250 operating underground mines.

These sources are responsible for at least 10 percent of United States (U.S.) anthropogenic methane emissions. Reducing methane emissions, which has a high greenhouse gas warming potential and will ameliorate climate change.

On May 19, 2021, ARPA-E announced up to $40 million in funding for **ONWARDS** (Optimizing Nuclear Waste and Advanced Reactor Disposal Systems).

The next generation of advanced nuclear reactors (AR) is currently being developed to enhance the safety, reduce the cost, and increase the efficiency of nuclear power generation. The future deployment of ARs will ensure that the U.S. meets its goals of greenhouse gas (GHG) reduction and facilitates U.S. energy security and global thought leadership in advanced nuclear energy. To enable the growth of advanced nuclear energy, ONWARDS seeks to develop and demonstrate breakthrough technologies that will facilitate a 10x reduction in AR waste volume generation or repository footprint. In addition, ONWARDS aims to advance development of high-performance AR waste forms while maintaining exemplary safeguards standards and global back-end costs in the accepted range of $1/megawatt-hour.

IV. Project Selections

In FY 2021, ARPA-E selected 109 projects across 15 funding opportunities[13] for a total of $205.6 million in funding.

[13] Including NEXTCAR Phase II, SCALEUP, SHARKS, ULTIMATE, Solicitations on Topics Informing New Program Areas (Topics L – T), ECOSynBio, and REFUEL + IT.

The NEXTCAR FOA was issued in FY 2016 and the second phase of NEXTCAR, NEXTCAR Phase II, selected projects in FY 2021. The SCALEUP, SHARKS, ULTIMATE, Solicitations on Topics Informing New Program Areas (Topics L – R), and ECOSynBio funding opportunities were issued in FY 2020 with projects selected in FY 2021. The Solicitations on Topics Informing New Program Areas (Topics S and T) and the REFUEL + IT funding opportunities were issued in FY 2021 with projects selected in FY 2021.

The table below summarizes the projects selected in FY 2021.

Table 2: Summary of ARPA-E Projects Selected in FY 2021

Program	Funding Opportunity Announcement	Funding Opportunity FY	Funding Amount at Time of Announcement ($Million)[14]	Project Selection	Project Selection FY	Number of Projects	Funding Amount at Time of Project Selection ($ Million)[15]
NEXTCAR Phase II	4/12/2016	FY 2016	$18.0	3/11/2021	FY 2021	4	$18.0
SCALEUP[16]	12/17/2019	FY 2020	$75.0	1/12/2021	FY 2021	7	$47.0
SHARKS	4/9/2020	FY 2020	$38.0	11/24/2020	FY 2021	11	$35.0
ULTIMATE	4/21/2020	FY 2020	$28.0	11/18/2020	FY 2021	17	$16.0
Solicitation on Topics Informing New Program Areas (Topic L)	5/19/2020	FY 2020	$3.5	10/6/2020	FY 2021	3	$3.5
Solicitation on Topics Informing New Program Areas (Topic M)	5/21/2020	FY 2020	$4.0	10/14/2020	FY 2021	5	$4.0
Solicitation on Topics Informing New Program Areas (Topic N)	5/20/2020	FY 2020	$5.0	10/14/2020	FY 2021	5	$5.0
Solicitation on Topics Informing New Program Areas (Topic O)	5/20/2020	FY 2020	$2.0	10/20/2020	FY 2021	3	$2.0

[14] Funding levels shown in this column are the amounts at the time of the FOA. The final funding amount may change by the time of project selection.
[15] Funding levels shown in in this column are as of the date of the project selection. The final number of projects and funding amounts are subject to change based on award negotiations and ongoing program management.
[16] This excludes the selections under the SCALEUP "Fast Track" option, which occurred in FY 2020.

Table 2: Summary of ARPA-E Projects Selected in FY 2021							
Program	**Funding Opportunity Announcement**	**Funding Opportunity FY**	**Funding Amount at Time of Announcement ($Million)[14]**	**Project Selection**	**Project Selection FY**	**Number of Projects**	**Funding Amount at Time of Project Selection ($ Million)[15]**
Solicitation on Topics Informing New Program Areas (Topic P)	5/20/2020	FY 2020	$2.0	10/20/2020	FY 2021	3	$2.0
ECOSynBio	9/10/2020	FY 2020	$25.0	5/14/2021	FY 2021	15	$35.0
Solicitation on Topics Informing New Program Areas (Topic Q)	9/17/2020	FY 2020	$10.0	2/25/2021	FY 2021	6	$10.0
Solicitation on Topics Informing New Program Areas (Topic R)	9/23/2020	FY 2020	$5.0	3/4/2021	FY 2021	4	$4.5
Solicitation on Topics Informing New Program Areas (Topic S)[17]	10/8/2020	FY 2021	$4.0	3/4/2021	FY 2021	5	$4.0
Solicitation on Topics Informing New Program Areas (Topic T)[18]	11/12/2020	FY 2021	$10.0	3/31/2021	FY 2021	20	$9.6
REFUEL + IT[19]	11/20/2020	FY 2021	$10.0	8/6/2021	FY 2021	1	$10.0

In FY 2021, ARPA-E selected 109 projects across 15 funding opportunities for a total of $205.6 million[20] in funding.

[17] This funding opportunity was also included in Table 1 of section III: FOAs because the funding opportunity was announced in FY 2021 and the project selections occurred in FY 2021.
[18] This funding opportunity was also included in Table 1 of section III: FOAs because the funding opportunity was announced in FY 2021 and the project selections occurred in FY 2021.
[19] This funding opportunity was also included in Table 1 of section III: FOAs because the funding opportunity was announced in FY 2021 and the project selections occurred in FY 2021.
[20] Funding levels shown in in this section are as of the date of each project's selection. The final number of projects and funding amounts are subject to change based on award negotiations and ongoing program management.

Summary and Details of projects selected in FY 2021:

On March 11, 2021, ARPA-E selected four projects to receive $18 million through **NEXTCAR Phase II** (Next-Generation Energy Technologies for Connected and Automated On-Road Vehicles Phase II).

Recent rapid advances in driver assistance technologies and the deployment of vehicles with increased levels of connectivity and automation have created multiple opportunities to improve the efficiency of future vehicle fleets in new ways. The projects that make up ARPA-E's NEXTCAR Program are enabling technologies that use connectivity and automation to co-optimize vehicle dynamic controls and powertrain operation, thereby reducing vehicle energy consumption. Vehicle dynamic and powertrain control technologies, implemented on a single vehicle basis, across a cohort of cooperating vehicles, or across the entire vehicle fleet could significantly improve individual vehicle—and ultimately, fleet—energy efficiency.

Example NEXTCAR Phase II Project: Michigan Technological University – "Connected and Automated Control for Vehicle Dynamics and Powertrain Operation on Light-Duty Electrified Vehicles" – Houghton, Michigan ($4,498,650).

In the NEXTCAR program, Michigan Technological University and its partners developed vehicle dynamics and powertrain model-based predictive controllers and optimizers using a variety of real-time information about vehicle, traffic, and roadway conditions and route characteristics to improve plug-in hybrid electric vehicle (PHEV) energy efficiency. The team achieved a 21 percent reduction in energy use over a representative drive cycle demonstrated on road and in simulation. In the next phase of NEXTCAR, the team will expand its set of test vehicles to include a Chevrolet Bolt electric vehicle, Chrysler Pacifica PHEV, and a 48-volt (48V) mild hybrid (electric assist) Ram pickup truck. The team will leverage connectivity and Level 4 (L4) automation to identify additional opportunities for fuel savings and electric vehicle (EV) range optimization in partnership with the American Center of Mobility, Stellantis, and General Motors.

On January 12, 2021, ARPA-E selected seven projects to receive $47 million through **SCALEUP** (Seeding Critical Advances for Leading Energy technologies with Untapped Potential).

The SCALEUP program enables promising ARPA-E projects to address the "scaling gap" and retire technical risks associated with productization, manufacturing, and deployment in real energy systems. SCALEUP is a first-of-its-kind initiative, supporting the scaling of high-risk and potentially disruptive new technologies across the full spectrum of energy applications. The goal of the program is to translate the performance achieved at the lab-and bench-scale to commercially viable versions of the technology.

Example SCALEUP Project: SkyCool Systems, Inc. – "Saving Energy in Commercial and Industrial Refrigeration Systems Using Radiative Sky Cooling" – Mountain View, CA ($3,500,000).

As part of SCALEUP, SkyCool aims to scale the manufacturing of its radiative cooling panels, train heating, ventilation, air conditioning and refrigeration (HVAC/R), and energy service company partners to install panel arrays and deploy panel arrays as an efficiency add-on to existing large scale cooling systems. Under SCALEUP, SkyCool will develop a mature performance model of its radiative cooling system with demonstrated energy savings from installations with key supermarket and cold storage facility operators. The success of the proposed project will validate the commercial scalability of SkyCool's solution and provide for accelerated market adoption of radiative cooling panels as an efficiency add-on.

SkyCool Systems has developed a passive radiative cooling technology that improves the energy efficiency of air conditioning and refrigeration systems by up to 40 percent. SkyCool's breakthrough rooftop panel system delivers a radiative cooling effect day and night by continuously rejecting heat into the depths of outer space. The panels cool without evaporating water and only require electricity to run a small circulation pump. The radiative cooling effect from SkyCool's panels occurs all day and night, which aligns with the 24/7 operation of cooling systems in supermarkets and cold storage facilities.

On November 24, 2020, ARPA-E selected 11 projects to receive $35 million through **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. Despite these attractive qualities, current HKTs are too expensive for deployment due to technical challenges and harsh operational environments. 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, co-design, and designing for operation and maintenance methodologies. These three methodologies require a wide range of disciplines to work concurrently, as opposed to sequentially, during the concept design stage. In addition, technical and environmental challenges inhibiting the convergence of HKT designs require expertise from various scientific and engineering fields, necessitating the use of multi-disciplinary teams.

These teams may include experts in hydrodynamics, mechanical design, materials, hydro-structural interactions, turbine and/or turbine array efficiency, system-level control solutions, power electronics, grid connection, numerical modeling, computer tools, and experimental validation. Projects will need to reduce the LCOE through multiple approaches, including increasing generation efficiency, increasing rotor area per unit of equivalent mass, lowering operation and maintenance costs, minimizing potential negative impacts on the surrounding environment, and maximizing system reliability among others.

Example SHARKS Project: Westergaard Solutions – "HydroMINE: Simple, Modular and Scalable" – Houston, TX ($1,600,000).

HydroMINE is a disruptive and elegantly simple modular system with a relatively small internal propeller driven by pressure from a stationary hydrofoil structure to a separate, internal flow stream. The internal propeller drives an ordinary electric direct drive generator. The size of the stationary HydroMINE hydrofoil structure is comparable to an equivalent ordinary rotor of the same swept area producing a similar amount of energy. The external floating structure is passive, only yawing slowly with the ocean tide or river flow direction. The internal propeller is isolated from debris and wildlife, so HydroMINE is safe for the marine environment, and extremely robust. It has a low maintenance cost, resulting in a lower cost of energy. It is manufactured with steel plates with the existing supply chain and integrates easily with ordinary marine structures for flexible deployments. The design is scalable from a community size (kilowatt) to utility level (multi-megawatt), making HydroMINE immediately commercially relevant.

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

The ULTIMATE program targets gas turbine applications in the power generation and aviation industries. ULTIMATE aims to develop ultrahigh temperature materials for gas turbines, enabling them to operate continuously at 1300 °C (2372 °F) in a stand-alone material test environment—or with coatings, enabling gas turbine inlet temperatures of 1800° C (3272° F) or higher. The successful materials must be able to withstand not only the highest temperature in a turbine but also the extreme stresses imposed on turbine blades. This program will concurrently develop manufacturing processes for turbine components using these materials, enabling complex geometries that can be seamlessly integrated in the system design. Environmental barrier coatings and thermal barrier coatings are within the scope of this program.

ULTIMATE consists of two separate phases, which may be proposed for a maximum of 18 and 24 months, respectively. In phase I, project teams will demonstrate proof of concept of their alloy compositions, coatings, and manufacturing processes through modeling and laboratory scale tensile coupon (sample) testing of basic properties. In phase II, approved project teams will investigate selected alloy compositions and coatings to evaluate a comprehensive suite of physical, chemical, and mechanical properties, as well as produce generic small-scale turbine blades to demonstrate manufacturability.

Example ULTIMATE Project: West Virginia University – "High-Throughput Computational Guided Development of Refractory Complex Concentrated Alloys-based Composite – Morgantown, WV ($700,000).

West Virginia University seeks to commercialize alloys and manufacturing processes to improve the overall safety, energy efficiency, and environmental performance of air travel and

electricity generation. The team will develop a new class of ultra-high temperature refractory complex concentrated alloys-based composites (RCCC) for high temperature applications such as combustion turbines used in the aerospace and energy industries. The approach is based on a transformative "high-entropy" strategy. The RCCC will consist of Refractory Complex Concentrated Alloys (RCCA) mixed with nanosized particles of refractory high entropy carbides, to increase RCCA strength to withstand extreme conditions. The goal is to optimize the balance among strength, creep (deformation), density, and stability at 1300 °C , while maintaining ductility once the alloy cools to room temperature. The research team will develop a specialty 3-D metal printing process to produce test coupons and potentially components such as turbine blades.

From October 6, 2020, to March 31, 2021, ARPA-E selected 54 Exploratory Topic projects to receive $44.6 million through **Solicitation on Topics Informing New Program Areas** (Topics L–T).

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.

In FY 2021, 54 projects were selected across nine topics: (1) Topic L, Insulating Nanofluids and Solids to Upgrade our Large Aging Transformer Equipment; (2) Topic M, Mining Incinerated Disposal Ash Streams; (3) Topic N, Waste into X; (4) Topic O, Direct Removal of Carbon Dioxide from Oceanwater; (5) Topic P: Direct Removal of Carbon Dioxide from Ambient Air; (6) Topic Q, Connecting Aviation By Lighter Electrical Systems; (7) Topic R, Lowering CO2: Models to Optimize Train Infrastructure, Vehicles, and Energy Storage; (8) Topic S, Topology Optimization and Additive Manufacturing for Performance Enhancement of High Temperature and High Pressure Heat Exchangers; (9) Topic T, Supporting Entrepreneurial Energy Discoveries (SEED).

On May 14, 2021, ARPA-E selected 15 projects to receive $35 million through **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.

Proposed systems of interest include, among others: (1) carbon-optimized fermentation strains that avoid carbon dioxide (CO_2) waste; (2) engineered organisms that can use a mix of different sources of energy and carbon, and avoid evolving CO_2; (3) biomass-derived sugar or carbon oxide gas fermentation with internal CO_2 recycling; (4) cell-free carbon-optimized biocatalytic

biomass conversion and/or CO_2 use; and (5) cross-cutting carbon-optimized bioconversion methods not otherwise described but having the potential for high-impact emissions reductions. All systems will need to be engineered to accommodate external reducing equivalents to optimize the carbon flux and overall system carbon efficiency relative to traditional fermentation or other bioconversion pathways (i.e., the sum of the recoverable energy products should be greater than the energy content of the primary carbon feedstock). Applicants are encouraged to use external reducing equivalent sources that can be produced electrocatalytically using water (H_2O), CO_2, or both.

Example ECOSynBio Project: ZymoChem – "Development of Carbon-Conserving Biosynthetic Systems Co-Utilizing C1 and Biomass Derived Feedstocks" – San Leandro, CA ($3,177,642).

ZymoChem will develop carbon- and energy-efficient biocatalysts capable of co-conversion of one-carbon molecules and biomass-derived substrates to a high-volume platform fuel and chemical intermediate. The team will demonstrate a carbon-conserving process decoupling growth and production. Most bioprocesses using microbes and renewable feedstocks to make fuels and chemicals are unprofitable, precluding their adoption on the industrial scale. When most microbes convert renewable feedstocks to fuels and industrial chemicals, they waste more than 33 percent of the input carbon in the form of CO_2 during production. The process will enable improved carbon efficiency during the growth phase and 100 percent carbon-efficient production of bioproducts during the production phase, using biomass-derived sugars and methanol as a reducing equivalent carrier. If successful, this project will create a new foundation for commercially attractive carbon-efficient bioprocesses.

On August 4, 2021, ARPA-E selected one project to receive $10 million through **REFUEL + IT**.

In 2016, ARPA-E launched the REFUEL program to develop technologies to convert air and water into CNLF. The goal was for CNLF developed under REFUEL to be stored, transported, and later converted into hydrogen or electricity to provide power for transportation applications in the same way as currently used petroleum-based fuels. Over the course of the program, next-generation CNLF technologies were developed utilizing new fuel cell designs, new ammonia conversion and separation processes, and new membranes. As the program continued, ARPA-E began to see that to effectively scale and commercialize these CNLF technologies, there was a need to demonstrate and test them under realistic use-case scenarios.

To address this need, ARPA-E launched a supplemental program – REFUEL + IT – focused on the IT of the type of technologies developed within the REFUEL program. REFUEL + IT seeks to develop a TIP to demonstrate next-generation ammonia production from intermittent renewable energy in a test-bed environment and its use for energy generation.

Example REFUEL + IT Project: Research Triangle Institute (RTI) International – "Next-Generation Ammonia System Integration Utilizing Intermittent Renewable Power" – Research Triangle Park, North Carolina ($10,000,000).

RTI International and its partners will develop a TIP to demonstrate next-generation ammonia production from intermittent renewable energy in a skid-mounted, modular testbed that is responsive to locational marginal pricing of electricity. The project leverages the University of Minnesota West Central Research and Outreach Center's operational hybrid wind and solar-to-ammonia field site to integrate the most promising breakthrough technologies developed in ARPA-E's REFUEL program. The TIP aims to demonstrate a disruptive modular, flexible process to produce one metric ton of low-carbon ammonia per day. It can accommodate several downstream ammonia utilization technology demonstrations, including ammonia cracking, to produce hydrogen and power generation to further enable the vision and expand the markets for ammonia as an energy carrier.

Table 3 summarizes ARPA-E's programs to date. A full list of the projects selected during FY 2021 can be found in Appendix I. Additional information related to these projects is on ARPA-E's website: http://arpa-e.energy.gov.

Table 3: ARPA-E Programs to Date

Funding Year	PROGRAM NAME	NUMBER OF PROJECTS[21]	FUNDING AMOUNT ($ Million)[22]
PRIOR TO FY 2021	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

[21] Number of projects listed are at the time of project selection. The final number of projects are subject to change based on contract negotiations and ongoing program management.
[22] Funding amounts listed are at the time of project selection. The final funding amount is subject to change based on contract negotiations and ongoing program management.

Table 3: ARPA-E Programs to Date			
Funding Year	**PROGRAM NAME**	**NUMBER OF PROJECTS[21]**	**FUNDING AMOUNT ($ Million)[22]**
	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
	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

Table 3: ARPA-E Programs to Date			
Funding Year	**PROGRAM NAME**	**NUMBER OF PROJECTS[21]**	**FUNDING AMOUNT ($ Million)[22]**
	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 – K)	67	$69.7
	Grid Optimization (GO) Competition Challenge 1	10	$3.4

Table 3: ARPA-E Programs to Date			
Funding Year	**PROGRAM NAME**	**NUMBER OF PROJECTS[21]**	**FUNDING AMOUNT ($ Million)[22]**
	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
	Performance-based Energy Resource Feedback, Optimization, and Risk Management (PERFORM)	12	$30.5
	Generating Electricity Managed by Intelligent Nuclear Assets (GEMINA)	9	$27
	Breakthroughs Enabling Thermonuclear-fusion Energy (BETHE)	16	$35
	FLExible Carbon Capture and Storage (FLECCS)	12	$11.5
	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 "Fast Track"	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)	14	$29.0
	Rapid Encapsulation of Pipelines Avoiding Intensive Replacement (REPAIR)	10	$33
FY 2020 FOA / FY 2021 SECLECTION	Solicitation on Topics Informing New Project Areas (Topics L – R)	29	$31
	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	$35
	Seeding Critical Advances for Leading Energy technologies with Untapped Potential (SCALEUP)[23]	7	$47
FY 2021	Solicitation on Topics Informing New Project Areas (Topics S and T)	25	$13.6

[23] This excludes the SCALEUP "Fast Track" option, which was selected in FY 2020.

Table 3: ARPA-E Programs to Date			
Funding Year	**PROGRAM NAME**	**NUMBER OF PROJECTS[21]**	**FUNDING AMOUNT ($ Million)[22]**
	Renewable Energy to Fuels through Utilization of Energy-dense Liquids Integration and Testing (REFUEL + IT)[24]	1	$10
	Next-Generation Energy Technologies for Connected and Automated On-Road Vehicles Phase II (NEXTCAR Phase II)	4	$18
FY 2021 FOA / FY 2022 SELECTION	OPEN 2021	68	$175
	Reducing Emissions of Methane Every Day of the Year (REMEDY)	12	$35
	Optimizing Nuclear Waste and Advanced Reactor Disposal Systems (ONWARDS)	11	$36
	Solicitation on Topics Informing New Project Areas (Topic U)	4	$9.4
	TOTAL	**1,263**	**$2,954**

V. ARPA-E Energy Innovation Summit

The eleventh ARPA-E Energy Innovation Summit was held May 24-27, 2021. The event convened leaders from academia, business, and government to discuss the foremost energy issues, showcase cutting-edge energy technologies, and facilitate relationships to help move technologies toward deployment. In light of COVID-19-related travel restrictions and safety concerns, ARPA-E hosted the Summit on a fully virtual conference platform.

Throughout the four-day event, attendees had the opportunity to watch high-level speakers and thought leaders on the Summit's Main Stage, engage with dynamic breakout panels, participate in virtual networking opportunities, and visit interactive virtual booths at the Technology Showcase. The Summit's popular Technology Showcase featured presentations, displays, and virtual booths from ARPA-E performers and a highly select group of other companies, stakeholders, and research organizations who exhibited the cutting-edge energy technologies funded across ARPA-E's many energy technology development programs.

[24] The REFUEL FOA was issued in FY 2016. The REFUEL + IT FOA was issued in FY 2021 to build off the technologies developed in the REFUEL program.

ARPA-E Energy Innovation Summit Highlights:

- More than 3,000 registered attendees from 49 states and 24 countries.
- More than 400 virtual exhibitor booths displaying transformational technologies from ARPA-E awardees and other innovative companies.
- More than 100 speakers and keynote addresses, including Cabinet Secretaries, Chief Executive Officers, and entrepreneurs working to design the energy systems and technologies of the future.
- Engaging panel discussions and interactive virtual networking opportunities that enabled participants to meet with ARPA-E program directors, global industry leaders, and energy technologists.
- 6,450 1:1 video chats between Summit attendees.
- A record-number of Student Program participants, with more than 300 students from 40 states and 100 higher-education institutions.

VI. Conclusion

In FY 2021, ARPA-E announced seven funding opportunities. The projects selected through these solicitations cover a wide range of technical areas:

1. **REFUEL + IT:** demonstrating next-generation ammonia production from intermittent renewable energy in a test-bed environment and its use for energy generation;

2. **OPEN 2021:** supporting the development of potentially disruptive new technology across the full spectrum of energy applications;

3. **REMEDY:** reducing methane emissions from the oil, gas, and coal value chain;

4. **ONWARDS:** enhancing the safety, reducing the costs, and increasing the efficiency of nuclear power generation; and

5. **Solicitation on Topics Informing New Program Areas:** Three Exploratory Topics exploring new areas of technology.

In FY 2021, ARPA-E selected **109** projects across 15 funding opportunities for a total of $205.6 million in funding:

1. **NEXTCAR Phase II:** leverage the advances of connected and automated vehicle technologies to further improve the energy efficiency of individual vehicles;

2. **SCALEUP:** scale up promising energy technologies to the pre-pilot stage of the path to market and ultimately realizing commercial impact;

3. **SHARKS:** develop new technical pathways to design economically competitive HKT for tidal and riverine currents;

4. **ULTIMATE:** develop ultrahigh temperature materials for gas turbines for applications in the power generation and aviation industries;

5. **Solicitation on Topics Informing New Program Areas:** nine Exploratory Topics to explore new areas of technology;

6. **ECOSynBio:** promote the use of advanced synthetic biology tools to engineer novel biomass conversion platforms and systems; and

7. **REFUEL + IT:** demonstrate next-generation ammonia production from intermittent renewable energy in a test-bed environment and its use for energy generation.

The statutory goals of ARPA-E are to:

1. Enhance economic and energy security of the U.S. through the development of energy technologies that reduce imports of energy from foreign sources; reduce energy-related emissions, including greenhouse gases; improve the energy efficiency of all economic sectors; provide transformative solutions to improve the management, clean-up, and disposal of radioactive waste and spent nuclear fuel; and improve the resilience, reliability, and security of infrastructure to produce, deliver, and store energy; and
2. Maintain the U.S. technological lead in the development and deployment of advanced energy technologies.

ARPA-E will continue to catalyze and accelerate the development of transformational energy technologies that could enable a more secure and affordable energy future in America and achieve ARPA-E statutory goals. ARPA-E will maintain the use of its successful model to select projects through "focused" and "open" programs, quickly and effectively leveraging new scientific discoveries and market developments. In addition, ARPA-E will track and evaluate the success of awardee technologies after their participation in a funding program in order to assess the transformative effects of ARPA-E's investments more clearly.

VII. Appendix I: Projects Selected in FY 2021

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

Appendix 1: Projects Selected in FY 2021				
Program	**Lead Organization**	**Project Title**	**Location**	**ARPA-E Funding**
SHARKS	Aquantis	Tidal Power Tug	Santa Barbara, California	$4,429,986
SHARKS	Emrgy	Performance Enhancement of Hydrokinetic Arrays Using Reliable, Low-Cost Dynamic Components	Atlanta, Georgia	$3,342,856
SHARKS	Littoral Power Systems	Control Co-design and Co-optimization of a Transformational Cost-Efficient Hydrokinetic Energy Turbine System	New Bedford, Massachusetts	$3,517,507
SHARKS	National Renewable Energy Laboratory (NREL)	A Computer Tool to Control Co-Design Hydrokinetic Energy Systems	Golden, Colorado	$1,200,000
SHARKS	Ocean Renewable Power Company (ORPC)	Optimized Hydrokinetic Systems	Portland, Maine	$3,576,987
SHARKS	SRI International	MANTA: Reliable and Safe Kite Energy System	Menlo Park, California	$4,194,000
SHARKS	University of Alaska Fairbanks	Material and Cost Efficient Modular Riverine Hydrokinetic Energy System	Fairbanks, Alaska	$3,333,360
SHARKS	University of Michigan	RAFT: Reconfigurable Array of High-Efficiency Ducted Turbines for Hydrokinetic Energy Harvesting	Ann Arbor, Michigan	$3,900,000
SHARKS	University of Virginia	Bio-Inspired Renewable Energy (BIRE) for Highly-efficient Low-cost Riverine Hydrokinetics	Charlottesville, Virginia	$2,900,000
SHARKS	University of Washington	Confinement-Exploiting Cross-Flow Turbine Arrays	Seattle, Washington	$1,825,000
SHARKS	Westergaard Solutions	HydroMINE: Simple, Modular, and Scalable	Houston, Texas	$1,600,000
ULTIMATE	General Electric (GE) Global Research	ULTIMATE Refractory Alloy Innovations for Superior Efficiency (RAISE)	Fairfield, Connecticut	$1,591,151
ULTIMATE	Massachusetts Institute of Technology (MIT)	Additive Manufacturing of Oxidation-Resistant Gradient Refractory Composites	Cambridge, Massachusetts	$600,000
ULTIMATE	National Energy Technology Laboratory	Rapid Design and Manufacturing of High-Performance Materials for Turbine Blades Applications above 1300°Celsius	Morgantown, West Virginia	$1,500,000

Appendix 1: Projects Selected in FY 2021				
Program	**Lead Organization**	**Project Title**	**Location**	**ARPA-E Funding**
ULTIMATE	Oak Ridge National Laboratory (ORNL)	Facility for Evaluating High Temperature Oxidation and Mechanical Properties	Oak Ridge, Tennessee	$1,500,000
ULTIMATE	Oak Ridge National Laboratory (ORNL)	Development of Niobium-Based Alloys for Turbine Applications	Oak Ridge, Tennessee	$700,000
ULTIMATE	Pacific Northwest National Laboratory (PNNL)	Selective Thermal Emission Coatings for Improved Turbine Performance	Richland, Washington	$599,999
ULTIMATE	Pennsylvania State University	Design and Manufacturing of Ultrahigh Temperature Refractory Alloys	University Park, Pennsylvania	$1,200,000
ULTIMATE	QuesTek Innovations	Concurrent Design of a Multimaterial Niobium Alloy System for Next-generation Turbine Applications	Evanston, Illinois	$1,039,950
ULTIMATE	Raytheon Technologies Research Center	Computationally Guided ODS Refractory HEAs via Additive Manufacturing	East Hartford, Connecticut	$799,882
ULTIMATE	Raytheon Technologies Research Center	Environmental Protection Coating System for Refractory Metal Alloys (EPCS for RMAs)	East Hartford, Connecticut	$699,956
ULTIMATE	Texas A&M University	Batch-wise Improvement in Reduced Design Space using a Holistic Optimization Technique (BIRDSHOT)	College Station, Texas	$1,200,000
ULTIMATE	University of Maryland	New Environmental-Thermal Barrier Coatings for Ultrahigh Temperature Alloys	College Park, Maryland	$600,000
ULTIMATE	University of Utah	Designing Novel Multicomponent Niobium Alloys for High Temperature: Integrated Design, Rapid Processing & Validation Approach	Salt Lake City, Utah	$800,000
ULTIMATE	University of Virginia	High Entropy Rare-earth Oxide (HERO) Coatings for Refractory Alloys	Charlottesville, Virginia	$600,000
ULTIMATE	University of Wisconsin-Madison	Additive Manufacturing of Ultrahigh Temperature Refractory Metal Alloys	Madison, Wisconsin	$650,000
ULTIMATE	West Virginia University	Additive Manufacturing of Ultrahigh Temperature Refractory Metal Alloys	Morgantown, West Virginia	$700,000
NEXTCAR Phase II	University of California, Berkeley	Predictive Vehicle Control – from ECU to the Cloud	Berkeley, California	3,474,864
NEXTCAR Phase II	Michigan Technological University	Connected and Automated Control for Vehicle Dynamics and	Houghton, Michigan	4,498,650

Appendix 1: Projects Selected in FY 2021				
Program	**Lead Organization**	**Project Title**	**Location**	**ARPA-E Funding**
		Powertrain Operation on Light-Duty Electrified Vehicles		
NEXTCAR Phase II	The Ohio State University	Fuel Economy Optimization with Dynamic Skip Fire in a Connected and Automated Vehicle	Columbus, Ohio	4,933,933
NEXTCAR Phase II	Southwest Research Institute	Model Predictive Control for Energy Efficient Maneuvering of Connected Autonomous Vehicles	San Antonio, Texas	5,250,000
Solicitations on Topics Informing New Program Areas (Topic L)	General Electric (GE) Global Research	Ultra-high-Performance nano-Liquid Insulation for upgrading Large Power Transformers (UPLIfT)	Niskayuna, New York	$1,246,325
Solicitations on Topics Informing New Program Areas (Topic L)	University of Texas at Austin	Nanotechnology-Enabled Transformer Life Extension	Austin, Texas	$750,000
Solicitations on Topics Informing New Program Areas (Topic L)	C-Crete Technologies	Colloidally Ultrastable, Highly Insulating, and Thermally Conductive Nanofluid for Large Power Transformers	Stafford, Texas	$1,500,000
Solicitation on Topics Informing New Program Areas (Topic M)	Georgia Institute of Technology	Characterization and Recovery of Critical Metals from Municipal Solid Waste Incineration Ashes	Atlanta, Georgia	$728,376
Solicitation on Topics Informing New Program Areas (Topic M)	Massachusetts Institute of Technology (MIT)	Electrochemical Mining of MSWI Ash	Cambridge, Massachusetts	$1,200,000
Solicitation on Topics Informing New Program Areas (Topic M)	Virginia Polytechnic Institute and State University	Physical, Chemical, and Mineralogical Characterizations of MSWI Ash Product and Recommendations for Downstream Processing	Blacksburg, Virginia	$500,000
Solicitation on Topics Informing New Program Areas (Topic M)	Columbia University	Integrated CO_2-facilitated Hydrometallurgical and Electrochemical Technology for Sustainable Mining and Recovery of Critical Elements from Wastes and Ashes	New York, New York	$400,000
Solicitation on Topics Informing New Program Areas (Topic M)	Lizivia, Inc.	Using Bio-inspired Lixiviants to Selectively Extract Valuable Metals from Municipal Solid Waste Incinerator Ash	Santa Barbara, California	$1,100,758
Solicitation on Topics Informing New Program Areas (Topic N)	Rutgers University	Waste-to-Energy (WTE)-Derived Low-Carbon-Footprint Concrete (LCFC)	Piscataway, New Jersey	$1,000,000

Appendix 1: Projects Selected in FY 2021				
Program	**Lead Organization**	**Project Title**	**Location**	**ARPA-E Funding**
Solicitation on Topics Informing New Program Areas (Topic N)	City University of New York: City College	Gypsum & Clay-Based Additives to MSW for Pre-Combustion Enhancement of Syngas and Solid Residue Improvement	New York, New York	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic N)	Glass Wrx SC, LLC	Industrial-scale Upcycling of Municipal Solid Waste Incinerator Ash into Engineered Cellular Magmatics	Beaufort, South Carolina	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic N)	University of Illinois	Rapid AI-based Dissection of Ashes using Raman and XRF Spectroscopy (RADAR-X)	Champaign, Illinois	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic N)	Designs by Natural Processes, Inc.	Making Cement at Ambient Temperature Using 55% Municipal Solid Waste Ash	Winona, Minnesota	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic O)	California Institute of Technology	Development of an Off-Shore, Stand-Alone System for Efficient CO_2 Removal from Oceanwater	Pasadena, California	$850,000
Solicitation on Topics Informing New Program Areas (Topic O)	University of North Dakota Energy & Environmental Research Center	Hydrolytic Softening of Ocean Water for Carbon Dioxide Removal	Grand Forks, North Dakota	$500,000
Solicitation on Topics Informing New Program Areas (Topic O)	Massachusetts Institute of Technology (MIT)	Electrochemically Modulated CO_2 Removal from Ocean Waters	Cambridge, Massachusetts	$650,000
Solicitation on Topics Informing New Program Areas (Topic P)	University of Michigan	Electrochemical Direct Air Capture of CO_2 Using Redox-Active Textiles	Ann Arbor, Michigan	$431,915
Solicitation on Topics Informing New Program Areas (Topic P)	Georgia Institute of Technology	Wind-Driven Direct Air Capture System Using 3D Printed, Passive, Amine-Loaded Contactors	Atlanta, Georgia	$783,738
Solicitation on Topics Informing New Program Areas (Topic P)	Creare LLC	High-Efficiency, Low-Cost, Additive-Manufactured Air Contactor	Hanover, New Hampshire	$784,347
ECOSynBio	Harvard University	CIRCE: Circularizing Industries by Raising Carbon Efficiency	Cambridge, Massachusetts	$2,985,025
ECOSynBio	Invizyne Technologies	Carbon Negative Chemical with Synthetic Biochemistry	Monrovia, California	$1,657,763
ECOSynBio	LanzaTech, Inc.	Carbon-Negative Chemical Production Platform	Skokie, Illinois	$4,160,263

Appendix 1: Projects Selected in FY 2021				
Program	**Lead Organization**	**Project Title**	**Location**	**ARPA-E Funding**
ECOSynBio	Massachusetts Institute of Technology (MIT)	Zero-Carbon Biofuels: An Optimized Two-Stage System for High Productivity Conversion of CO_2 to Liquid Fuels	Cambridge, Massachusetts	$2,108,532
ECOSynBio	National Renewable Energy Laboratory (NREL)	Formate as an Energy Source to Allow Sugar Fermentation with No Net CO_2 Generation: Integration of Electrochemistry with Fermentation	Golden, Colorado	$2,838,575
ECOSynBio	Stanford University	Disruptive Technology for Carbon Negative Commodity Biochemicals	Stanford, California	$2,672,672
ECOSynBio	The Ohio State University	A Novel Integrated Fermentation Process with Engineered Microbial Consortia for Butanol Production from Lignocellulose Sugars without CO_2 Emission	Columbus, Ohio	$1,611,940
ECOSynBio	University of California, Berkeley	A Microbial Consortium Enabling Complete Feedstock Conversion	Berkeley, California	$1,574,966
ECOSynBio	University of California, Irvine	Carbon-Efficient Conversion of Carboxylic Acids to Fuels and Chemicals	Irvine, California	$2,152,966
ECOSynBio	University of Delaware	Bioenergy Production Based on an Engineered Mixotrophic Consortium for Enhanced CO_2 Fixation	Newark, Delaware	$2,752,577
ECOSynBio	University of Minnesota	Cell-free Bioelectrocatalytic Platform for Carbon Dioxide Reduction	Minneapolis, Minnesota	$1,110,525
ECOSynBio	University of Washington	Self-Assembling Cell-Free Systems for Scalable Bioconversion	Seattle, Washington	$1,664,297
ECOSynBio	University of Wisconsin-Madison	Acetate as a Platform for Carbon-Negative Production of Renewable Fuels and Chemicals	Madison, Wisconsin	$3,421,197
ECOSynBio	ZymoChem	Development of a Bio-electrochemical Hybrid Fermentation Technology for the Carbon Conserving Production of Industrial Chemicals	San Leandro, California	$1,053,000
ECOSynBio	ZymoChem	Development of Carbon-Conserving Biosynthetic Systems Co-Utilizing C1 and Biomass Derived Feedstocks	San Leandro, California	$3,177,642
Solicitation on Topics Informing New Program Areas (Topic Q)	General Electric (GE) Global Research	Megawatt Any-Altitude Gas Insulated Cable system for aircraft power distribution (MAAGIC)	Niskayuna, New York	$3,448,797
Solicitation on Topics Informing	Illinois Institute of Technology	Superconducting Momentary Circuit Interrupter: Fault Protection with Ultralow Loss and Ultrafast	Chicago, Illinois	$779,374

Appendix 1: Projects Selected in FY 2021				
Program	**Lead Organization**	**Project Title**	**Location**	**ARPA-E Funding**
New Program Areas (Topic Q)		Response for Future Electric Aviation		
Solicitation on Topics Informing New Program Areas (Topic Q)	Virginia Polytechnic Institute and State University	High Power Density Cost-Effective MV DC Aircraft Cable	Blacksburg, Virginia	$1,171,829
Solicitation on Topics Informing New Program Areas (Topic Q)	University of Tennessee	Ultra-Light Tightly-Integrated Modular Aviation-Transportation Enabling Solid-State Circuit Breaker (ULTIMATE-SSCB)	Knoxville, Tennessee	$1,400,000
Solicitation on Topics Informing New Program Areas (Topic Q)	Advanced Conductor Technologies LLC	Lightweight, High-power Density, Self-protecting Superconducting Power Cables and Connectors for Electric Aircraft Applications	Boulder, Colorado	$1,600,000
Solicitation on Topics Informing New Program Areas (Topic Q)	HyperTech Research Inc.	Power Transmission Cable for Electric Aircraft using Bio LNG for Cooling and Thermal Management	Columbus, Ohio	$1,600,000
Solicitation on Topics Informing New Program Areas (Topic R)	North Carolina State University	Multi-Decadal Decarbonization Pathways for U.S. Freight Rail	Raleigh, North Carolina	$1,500,000
Solicitation on Topics Informing New Program Areas (Topic R)	Pennsylvania State University	Synthesis of Consists as Rolling Energy micro-grids (SCORE)	University Park, Pennsylvania	$1,000,000
Solicitation on Topics Informing New Program Areas (Topic R)	Northwestern University	LOwering CO_2: Models to Optimize Train Infrastructure, Vehicles, and Energy Storage (LOCOMOTIVES)	Evanston, Illinois	$500,000
Solicitation on Topics Informing New Program Areas (Topic R)	National Renewable Energy Laboratory (NREL)	ALTRIOS - Advanced Locomotive Technology and Rail Infrastructure Optimization System -	Golden, Colorado	$1,500,000
Solicitation on Topics Informing New Program Areas (Topic S)	Raytheon Technologies Research Center	Multi-Material Topology Optimization for High Performance Heat Exchangers	East Hartford, Connecticut	$999,821
Solicitation on Topics Informing New Program Areas (Topic S)	Siemens Corporation	Multi-Physics Topology Optimization for Dual Flow Heat Exchangers	Princeton, New Jersey	$627,747
Solicitation on Topics Informing New Program Areas (Topic S)	University of Connecticut	Topology Optimization Of Additively Manufactured Heat-Exchanger Plates For Enhanced Performance (TOP-HEX)	Storrs, Connecticut	$961,954

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Program	**Lead Organization**	**Project Title**	**Location**	**ARPA-E Funding**
Solicitation on Topics Informing New Program Areas (Topic S)	Boeing Research & Technology	Multidisciplinary Topology Optimization of Extreme Environment Heat Exchangers	Huntington Beach, California	$867,644
Solicitation on Topics Informing New Program Areas (Topic S)	University of Wisconsin-Madison	Multi-Physics Topology Optimization and Additive Manufacturing for High-Temperature Heat Exchangers	Madison, Wisconsin	$541,500
SCALEUP	AutoGrid Systems	Highly Scalable Virtual Power Plant (VPP) PLATFORM for Mass Storage and EV Deployments	Redwood City, California	$2,250,000
SCALEUP	Bridger Photonics	Scaling Disruptive Methane Leak Detection and Quantification	Bozeman, Montana	$4,572,000
SCALEUP	Cambridge Electronics	8” 3DGaN FinFET Technology for Energy Efficient Data Centers and 5G Network	Cambridge, Massachusetts	$4,320,000
SCALEUP	LongPath Technologies	Basin-SCAN: Basin Scale Continuous oil and gas emissions Abatement Network	Boulder, Colorado	$5,000,000
SCALEUP	Natron Energy	Domestic Manufacturing of Sodium-Ion Batteries	Santa Clara, California	$19,883,951
SCALEUP	SkyCool Systems	Saving Energy in Commercial and Industrial Refrigeration Systems Using Radiative Sky Cooling	Mountain View, California	$3,500,000
SCALEUP	Switched Source	Scaling Up Cost-Effective Grid Modernization	Vestal, New York	$8,560,000
Solicitation on Topics Informing New Program Areas (Topic T)	Nitricity, Inc.	Non-Equilibrium Plasma for Energy-Efficient Nitrogen Fixation	San Francisco, California	$500,000
Solicitation on Topics Informing New Program Areas (Topic T)	Heirloom Carbon dba EquiOpps	A Transformative Low-Cost Approach for Direct Air Mineralization of CO_2 via Repeated Cycles of Ambient Weathering of Metal Oxides	San Francisco, California	$476,811
Solicitation on Topics Informing New Program Areas (Topic T)	Living Carbon	Increasing Carbon Drawdown and Retention in Terrestrial Biomass using Bioengineered Trees	San Francisco, California	$500,000
Solicitation on Topics Informing New Program Areas (Topic T)	Micro Nano Technologies	Thermally Driven Industrial Semi-Open Absorption Heat Pump Dryer	Gainesville, Florida	$499,997
Solicitation on Topics Informing New Program Areas (Topic T)	NoMIS Power Group LLC	6.5 kV, 100 A SiC Power Module Technology to Meet 21st Century Energy Demands	Newtonville, New York	$498,297

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Solicitation on Topics Informing New Program Areas (Topic T)	Adroit Materials	kV-class GaN-based Junction Barrier Schottky Diodes using ion implantation	Apex, North Carolina	$500,000
Solicitation on Topics Informing New Program Areas (Topic T)	Adroit Materials	Ion implantation-enabled fabrication of AlN based Schottky diodes	Apex, North Carolina	$500,000
Solicitation on Topics Informing New Program Areas (Topic T)	Blue Sky Measurements	Optical NIR Fixed-Position Passive Scanner for Methane Detection and Measurement	Houston, Texas	$499,500
Solicitation on Topics Informing New Program Areas (Topic T)	OCO Inc.	High Aspect Ratio CO_2 Reduction Electrolyzer via Novel Gas Diffusion Electrode - Design	Woodinville, Washington	$467,468
Solicitation on Topics Informing New Program Areas (Topic T)	Frost Methane Labs Co.	Design of Smart Micro-Flare Fleet to Mitigate Distributed Methane Emissions	Oakland, California	$451,676
Solicitation on Topics Informing New Program Areas (Topic T)	Giner, Inc.	Direct Air Capture Utilizing Hydrogen-Assisted Carbonate Electrolysis	Newton, Massachusetts	$500,000
Solicitation on Topics Informing New Program Areas (Topic T)	Mosaic Materials, Inc.	Integration of Ultrahigh Capacity Sorbents into Direct Air Capture Systems	Alameda, California	$499,968
Solicitation on Topics Informing New Program Areas (Topic T)	InventWood LLC	Wood Honeycombs for Lightweight, Energy Efficient Structural Applications	College Park, Maryland	$500,000
Solicitation on Topics Informing New Program Areas (Topic T)	Origen Hydrogen	Engineering of Scalable Platinum-free Electrodes for Pure-Water AEM Water Electrolysis	Palo Alto, California	$396,000
Solicitation on Topics Informing New Program Areas (Topic T)	Electrified Thermal Solutions	Firebrick Resistance-heated Energy Storage (FIRES)	Somerville, Massachusetts	$500,000
Solicitation on Topics Informing New Program Areas (Topic T)	Big Blue Technologies LLC	Carbon Negative Magnesium Metal Production Using a Cyclic Batch High Temperature Condenser	Westminster, Colorado	$500,000
Solicitation on Topics Informing	Phoenix Tailings, Inc.	Novel Technique for Domestic Rare Earth Oxide Separation and Rare Earth Metal Reduction	Woburn, Massachusetts	$499,855

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Program	**Lead Organization**	**Project Title**	**Location**	**ARPA-E Funding**
New Program Areas (Topic T)				
Solicitation on Topics Informing New Program Areas (Topic T)	Sublime Systems	Electrochemical Synthesis of Low-Carbon Cement	Weston, Massachusetts	$498,253
Solicitation on Topics Informing New Program Areas (Topic T)	XFlow Energy Company	Low-Cost Wind Energy Through Dense VAWT Arrays: Fatigue Loads and Power Performance Risk Mitigation	Cambridge, Massachusetts	$500,000
Solicitation on Topics Informing New Program Areas (Topic T)	SiTration, Inc.	Low-Cost Recycling of Lithium from Batteries via Conductive Membrane Nanofiltration	Cambridge, Massachusetts	$320,000
REFUEL + IT	Research Triangle Institute (RTI) International	Next-Generation Ammonia System Integration Utilizing Intermittent Renewable Power	Research Triangle Park, North Carolina	$10,000,000