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Advanced Research Projects Agency • ENERGY

FY2010 Annual Report

U.S. DEPARTMENT OF ENERGY

Advanced Research Projects Agency-Energy FY2010 Annual Report

Pursuant to statutory requirements of P.L. 110-69 and P.L. 111-358, the Director of ARPA-E is providing a report describing projects supported by the Agency during fiscal year 2010 to the Chairman and Ranking Member of relevant authorizing and appropriations committees of Congress.

The Honorable Fred Upton
Chairman, House Committee on Energy and Commerce

The Honorable Henry Waxman
Ranking Member, House Committee on Energy and Commerce

The Honorable Ralph Hall
Chairman, House Committee on Science, Space & Technology

The Honorable Eddie Bernice Johnson
Ranking Member, House Committee on Science, Space & Technology

The Honorable Andy Harris
Chairman, Subcommittee on Energy and Environment, House Committee on Science, Space & Technology

The Honorable Brad Miller
Ranking Member, Subcommittee on Energy and Environment, House Committee on Science, Space & Technology

The Honorable Hal Rogers
Chairman, House Committee on Appropriations

The Honorable Norman Dicks
Ranking Member, House Committee on Appropriations

The Honorable Rodney Frelinghuysen
Chairman, Energy and Water Development Subcommittee, House Committee on Appropriations

The Honorable Pete Visclosky
Ranking Member, Energy and Water Development Subcommittee, House Committee on Appropriations

The Honorable Jeff Bingaman
Chairman, Senate Committee on Energy & Natural Resources

The Honorable Lisa Murkowski
Ranking Member, Senate Committee on Energy & Natural Resources

The Honorable Maria Cantwell
Chairman, Subcommittee on Energy, Senate Committee on Energy and Natural Resources

The Honorable James Risch
Ranking Member, Subcommitee on Energy, Senate Committee on Energy and Natural Resources

The Honorable Daniel Inouye
Chairman, Senate Committee on Appropriations

The Honorable Thad Cochran
Ranking Member, Senate Committee on Appropriations

The Honorable Dianne Feinstein
Chairman, Subcommittee on Energy and Water Development, Senate Committee on Appropriations

The Honorable Lamar Alexander
Ranking Member, Subcommittee on Energy and Water Development, Senate Committee on Appropriations

Message from the Director

ARPA-E's deeply engaged and dedicated team has the same aspiration that all Americans share: to leave the world far better for our children than the world that we live in today. In a world where populations and economies are growing steadily, the demand for energy and material resources is expected to increase and will likely accelerate. The U.S. became an oil importer in the 1940s and now imports more than 50 percent of the oil it uses. China, India and many growing economies are oil importers as well. Given the constraints for energy resources, access to affordable energy has become, and will continue to be, a major national and economic security issue. The technologies needed to create sustainable economic growth using a domestic portfolio of resources do not exist today. Any nation that leads the world in these technologies will ensure its economic prosperity in the 21st century. There is a global competition going on to lead the world in this energy technology revolution. ARPA-E's goal is to ensure U.S. technological leadership by investing in and developing those technologies that are too risky for private sector investment, but if successful, will enhance the national, economic, and environmental security of our nation.

With the best research and development infrastructure in the world and a thriving innovation ecosystem in business and entrepreneurship, America has the ingredients necessary for success. American history is replete with examples of pioneers and entrepreneurs who took risks. They often failed initially, but quickly learned from those failures, competed against each other, and innovated in both technology and business to create the largest industrial base the world has ever seen. At ARPA-E, we tap into this truly American ethos to identify and support the pioneers of our future.

With the best research and development infrastructure in the world and a thriving innovation ecosystem in business and entrepreneurship, America has the ingredients necessary for success.

In our first two years of existence, ARPA-E's success, impact, and potential have been recognized by several influential reports[1,2,3]. We have recruited some of the most talented individuals from the science, technology, and business communities to join ARPA-E and serve the Nation. We have established new programs to fund teams of scientists and engineers in universities, national laboratories, and small and large businesses that are engaged in innovating those clean energy technologies that do not exist today, but if they did, they would make today's technologies obsolete and have large commercial impact. Examples include batteries for transportation beyond lithium-ion that would make electric cars cheaper and with longer range than those based on gasoline engines. ARPA-E's goal is to make clean energy technologies cheaper than traditional approaches so that they can scale without subsidies and enable sustainable businesses to grow.

ARPA-E is fast, nimble, adaptive, and focused, with a culture that emphasizes integrity, excellence, openness, and agility. We commit ourselves to: recruiting the best talent, excellence in everything we do, stepping up to the plate and taking ownership, openness in debate and discussion with “constructive confrontation,” and helping each other out when needed without compromising on our expectation of excellence.

We practice active program management and support our projects for up to three years. Our support makes it possible for the development of these transformational energy technologies to proceed by funding, on average, over three-quarters of total project costs.

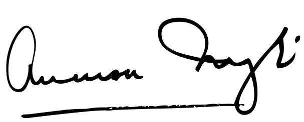
ARPA-E’s Fiscal Year 2010 Annual Report highlights the establishment of our agency, how we focus precious resources to create programs that will furthest advance the development of transformational technologies in energy, and the projects we have funded to date. In these first two years, ARPA-E has awarded amounts ranging from roughly $400,000 to $9 million each to 121 projects, with an average award value of $3 million. We practice active program management and support our projects for up to three years. Our support makes it possible for the development of these transformational energy technologies to proceed by funding, on average, over three-quarters of total project costs.

Although it is still very early, several of ARPA-E’s projects are showing technical and commercial successes as well as significant additional investment and venture formation activity. These are promising signs of the potential to achieve eventual commercialization success with some of these breakthrough technologies. In a little over one year, six projects that received a total of $23.6 million in seed funding from ARPA-E have generated more than $100 million in outside private capital investment. Leveraging private capital has enabled ARPA-E projects to accelerate technical development, aggressively create jobs, acquire capital equipment, and expand facilities.

I continue to be deeply grateful for this opportunity to be the first Director of ARPA-E. I have the highest quality team helping me and look forward to looking back ten to twenty years from now with very fond memories, in awe of the technological homeruns we will have hit.

Sincerely,

Arun Majumdar



Director, *Advanced Research Projects Agency-Energy*

1 President’s Council of Advisors for Science and Technology (PCAST). (November 2010). *Accelerating the Pace of Change in Energy Technologies through an Integrated Federal Energy Policy.* Washington, DC.

2 American Energy Innovation Council. (June 2010). *A Business plan for America’s Energy Future.* Washington, DC.

3 The Breakthrough Institute. (October 2010). *Post-Partisan Power: How a Limited and Direct Approach to Energy Innovation Can Deliver Clean, Cheap Energy, Economic Productivity and National Prosperity.* Oakland, CA.

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ARPA-E FY2010 Annual Report

1 | Energy Innovation: A National Priority

The Advanced Research Projects Agency-Energy (ARPA-E) was created by the United States Congress in 2007 to enhance our energy and economic security, strengthening national security through the way we generate, store, and use energy.

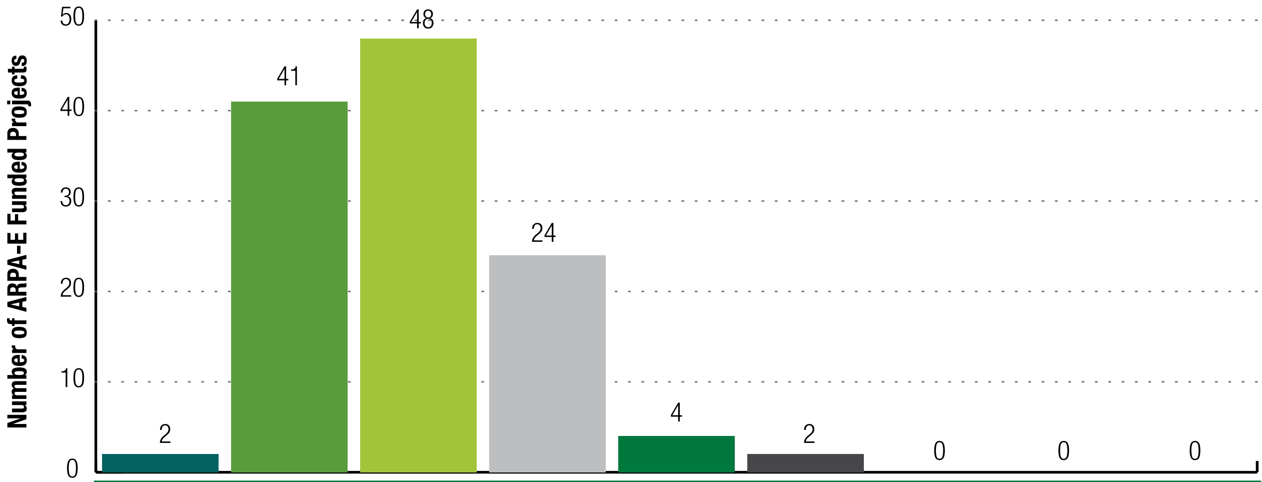
In 2005, a bipartisan group of Members of Congress requested that the National Academies "identify the most urgent challenges the U.S. faces in maintaining leadership in key areas of science and technology." In response, the National Academies authored a report entitled *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* in which grave concerns were expressed about the state of U.S. economic and technological competitiveness. Recognizing the U.S. need to stimulate innovation and develop clean, affordable, and reliable energy, the report recommended the creation of ARPA-E as a catalyst to accelerate the development of transformational energy technologies. Modeled after the successful Defense Advanced Research Projects Agency (DARPA), ARPA-E was intended to take a high-risk and high-impact route to innovation in energy. Much like DARPA's creation in 1958 in response to the launch of the Russian Sputnik space satellite, ARPA-E was created with the realization that the U.S. was losing its technological lead, specifically in energy. As President Barack Obama said in his 2011 State of the Union address, "This is our generation's Sputnik moment."

Through the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (America COMPETES) Act, Congress authorized the creation of ARPA-E in 2007. ARPA-E received initial funding of $400 million in FY2009 to accelerate the pace of innovation and to fund early-stage transformational energy research that industry by itself is unlikely to support because of technical and financial uncertainty. There is an inherent risk associated with the type of projects ARPA-E supports, and not all of ARPA-E's funded projects will be successful. However, those ARPA-E funded projects that are successful in reaching the marketplace stand to benefit the U.S. greatly through the creation of new industries and jobs, access to more cost-effective energy technologies, and an accelerated timeframe for achieving the Nation's energy goals.

ARPA-E invests in and manages the development of only transformational energy technologies that hold the potential to radically shift our Nation's energy reality. Transformational technologies are by definition those that disrupt the status quo. They do not seek evolutionary improvements—they drive revolutionary ones. They do not merely outperform current technologies—they make those technologies obsolete. ARPA-E aims to accelerate the development of transformational energy technologies at an early stage in their development cycle. Most ARPA-E funded projects range from technology concept (TRL 2) through component validation in laboratory experiment (TRL 4) technology readiness levels (TRL), a widely-used systematic measurement system that assesses technology maturity (See Figure 1). The TRL space between TRL 2 and TRL 4 is known as a "valley of death" for technology development: many private and public sector funders consider this nascent stage of development too high-risk for investment, even in concepts with promising technological potential.

To mitigate this risk, ARPA-E ensures its funding programs have commercial relevance—first, by considering potential market impact when developing new programs, and second, by incorporating market-relevant cost and performance criteria into each funding solicitation and the subsequent review and selection process. ARPA-E is specifically designed to assume and carefully manage this risk, providing crucial financial,

Figure 1 Project TRL prior to ARPA-E funding



TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Basic principles observed and reported	Technology concept and/or application formulated	Analytical and experimental critical function and/or characteristic proof of concept	Component and/or breadboard validation in laboratory environment	Component and/or breadboard validation in relevant environment	System/ subsystem model or prototype demonstration in relevant environment	System prototype demonstration in an operational environment	Actual system completed and qualified through test and demonstration	Actual system proven through successful mission operations

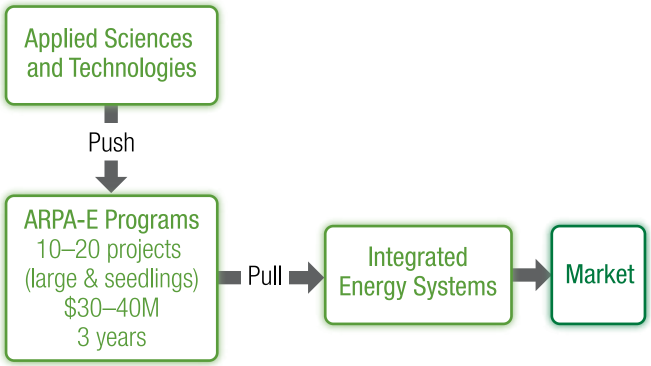
technical, and commercialization assistance to a diverse portfolio of projects. Additionally, ARPA-E performs active program management on its projects including monitoring quarterly technical milestones, visiting project sites frequently, and utilizing go/no-go decisions for project advancement. ARPA-E aims to promote the rapid development of technologies toward a point where private or public investors commit funds and bring them to market scale. With ARPA-E funding and support, projects typically advance to component validation in a relevant environment (TRL 5) through system prototype demonstration in an operational environment (TRL 7).

2 | A New Paradigm in Energy Research

Identifying Technological Areas of Need

ARPA-E's foundation rests upon open discussion across science, technology, and business. ARPA-E programs are created through a process of rigorous debate surrounding the technical/scientific merits and challenges of potential research areas and must satisfy both concepts of "technology push"—the technical merit of innovative platform technologies that can be applied to energy systems—and "market pull"—the potential market impact and cost-effectiveness of the technology (See Figure 2).

Figure 2 Technology Push and Market Pull



The detailed program creation process begins with a "deep dive": a process of thoroughly exploring an aspect of the energy problem to identify potential topics for program development. ARPA-E Program Directors then hold technical workshops to gather input from the world's leading experts about current state-of-the-art technologies and new technological opportunities that lie on the horizon. By bringing together experts from all walks of science, technology, and business, ARPA-E breaks down silos between disciplines. This cross-disciplinary inquiry is essential to bridge the gap between basic and applied research and development. ARPA-E workshops bring together the best and the brightest to identify technical challenges and opportunities that connect science to technology and markets—linking knowledge of what science is capable of to what technology can achieve and what the market needs. To date, ARPA-E has hosted or co-hosted 13 technical workshops (See Appendix A for detail on ARPA-E's past workshops).

Following each workshop, the Program Director proposes a new program and defends the program against a set of criteria that justifies its creation (See Figure 3). After intense, "constructive confrontation" and debate involving all ARPA-E Program Directors, the Program Director refines the program, incorporating internal and external feedback, and seeks approval from the Director. If successful, a new ARPA-E program is created, and a solicitiation, or funding opportunity announcement (FOA), is released, soliciting project proposals.

With project proposals in hand, the ARPA-E peer review process is designed to help drive toward subsequent program success. During proposal review, ARPA-E solicits external inputs to make sure that it is funding the best technologies. ARPA-E taps the expertise of dozens of the leading experts in the world in a particular field for in-depth proposal reviews. The involvement of world-class scientists, engineers, and leaders from the technical community brings expertise and knowledge to the process. ARPA-E reviewers evaluate applications over several weeks, and then come together for a review panel.

One notable facet of ARPA-E's evaluation process is ***the opportunity for the applicant to read reviewers' comments and to provide a rebuttal that the Agency reviews before making funding decisions***. The applicant response period allows ARPA-E to avoid misunderstandings by asking clarifying questions that enable ARPA-E to make the most informed decisions during the project selection process and identify the most compelling and meritorious ideas for support.

Figure 3 ARPA-E Program Creation Criteria

Program Technical Goals	▸ What is the global landscape of the field—science, technology, markets, players? ▸ If successful, what specifically will the program accomplish technically? ▸ Has the program been coordinated with DOE?
Mission Impact	▸ What impact would this success have on the agency mission when the technology becomes widely used—what's new and why is it a potential game-changer? ▸ How much better will the new technology be than existing technologies along quantitative metrics?
Technical Approach	▸ What are the key technical challenges and what are the ideas for overcoming these barriers?
Transition	▸ What is the transition strategy (risk profile and time horizon)? ▸ What are the non-technical barriers to transition (policy, markets)? Will technology scale in cost and volume? ▸ Who are the customers who will absorb this technology and who will potential players be?
Program Metrics	▸ What are the metrics, milestones, and schedule for this program? ▸ How much will the program cost and why?

ARPA-E is purposefully organized and administered to ensure agility, allowing the Agency to quickly implement changes in its processes to improve both efficiency and effectiveness. Through a forward-thinking operation style, ARPA-E strives to be a model of excellence as a small agency within the U.S. government.

ARPA-E recruits top caliber talent from the fields of science, engineering, and business to serve as Program Directors for limited terms, and empowers them to make technical and programmatic decisions for the projects they oversee. Above them are Deputy Directors and the Agency's Director, who in turn reports directly to the Secretary of Energy. This flat organizational structure gives ARPA-E the flexibility to take bold steps quickly.

ARPA-E has adopted several operational practices that are uncommon in the Energy Department. These innovations expedite the program development and project selection process without compromising quality or integrity, while aiming toward operational and mission success within rigid time constraints. For example, the quick negotiation of funding agreements is hallmark of the ARPA-E process. Dedicated procurement and legal teams embedded within the Agency improve efficiency. With this arrangement of embedded teams, ARPA-E is able to transfer awards from announcement to signed funding agreements, on average, in about two months. This speed and efficiency of process contributes to ARPA-E's success and positive reputation. During the award negotiation phase, the general cost and performance metrics developed for the program are negotiated with specificity for each selected performer. ARPA-E's cost and performance metrics are particularly aggressive, seeking not to advance the prevailing technology up existing learning curves, but rather to establish entirely new learning curves that can potentially develop transformational energy technologies. These cost and performance metrics become technical deliverables and milestones for the selected projects and are codified in the funding agreement.

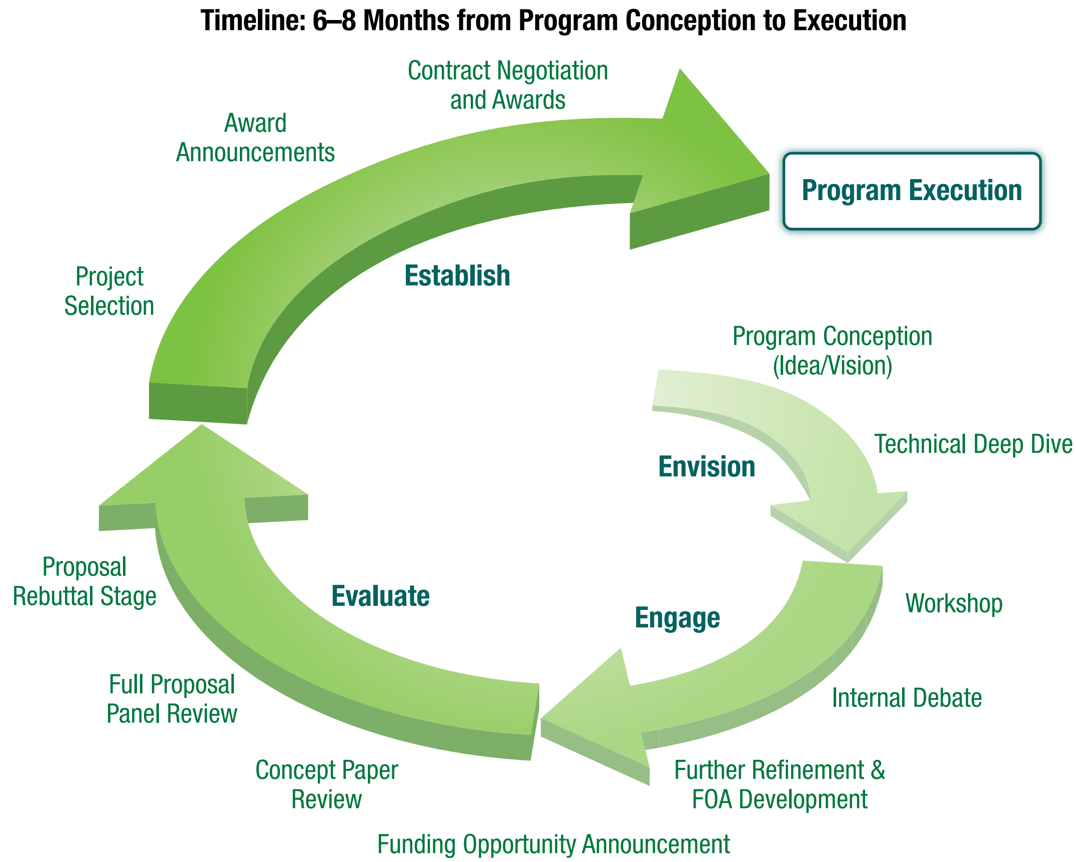
Harnessing the Nation's Intellectual Horsepower

ARPA-E projects are selected and funded based on the following differentiating characteristics:

- **High Impact:** ARPA-E funded projects enhance the economic and energy security of the U.S.; ensure U.S. technological lead in developing and deploying advanced energy technologies; and provide major economic impact and social improvements for Americans
- **Technological Breakthroughs:** ARPA-E identifies those disruptive energy technologies that can make current technologies obsolete
- **Value-Added:** ARPA-E program areas and selected projects advance the research and development of early-stage transformational technologies that is not being advanced by others
- **Best-in-Class Teams:** ARPA-E nurtures project development by coupling scientists and engineers in teams to rapidly advance technological innovation in energy, bringing together talented people from diverse areas of science, technology, and business that otherwise might not work together

ARPA-E's first open FOA was released in April 2009 and was open to all potentially disruptive energy technologies. Expecting 500 to 800 concept papers, the Agency received an overwhelming response of roughly 3,700 concept papers. ARPA-E invited the Nation's experts from academia, industry, and government to assist with reviewing the concept papers, and hundreds of reviewers participated. Through efficient operations, ARPA-E announced the projects selected for award negotiations within six months. ARPA-E funded 36 projects from this open FOA totaling $150 million. Projects selected for funding fall across the energy landscape, including projects for Energy Storage; Biomass Energy; Carbon Capture; Renewable Power;

Figure 4 ARPA-E Program Development Process



Solar Fuels; Vehicle Technologies; Waste Heat Capture; Building Efficiency; Conventional Energy; and Water.

To provide additional opportunities for exposure and collaboration, ARPA-E invited back many technically diverse experts whose projects were not funded during the initial FOA to participate in workshops, led by ARPA-E leadership, to brainstorm on the most promising opportunities for high-impact program areas for the next rounds of funding. Different from the initial open FOA, the second round of FOAs, announced in December 2009, focused on three new program areas known as Batteries for Electrical Energy Storage in Transportation (BEEST); Innovative Materials and Processes for Carbon Capture Technologies (IMPACCT); and Electrofuels. In April 2010, ARPA-E announced project selections for these program areas. 38 projects were awarded a total of $113 million.

In March 2010, ARPA-E announced its third round of funding opportunities and created programs that are known as: Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS); Building Energy Efficiency Through Innovative Thermodevices (BEETIT); and Agile Delivery of Electrical Power Technology (ADEPT). The project selections were announced in July 2010, and 42 projects are funded in these three programs with a total of $94 million.

In August 2010, ARPA-E selected five additional projects for funding. Projects selected for funding fell into the following energy areas: Building Efficiency; Vehicle Technologies; Renewable Power; and Energy Storage. ARPA-E announced the project selections in September 2010, for a total of $9 million.

3 | Putting Innovation into Action

ARPA-E currently supports 121 projects in the following areas:

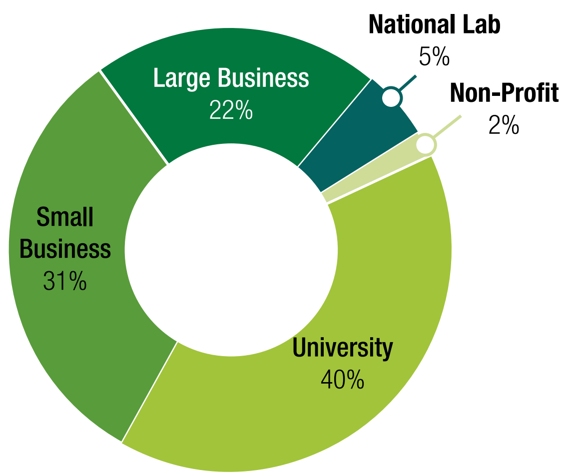
- Open Funding Opportunity Announcement and Other Projects
- Agile Delivery of Electrical Power Technology (ADEPT)
- Batteries for Electrical Energy Storage in Transportation (BEEST)
- Building Energy Efficiency Through Innovative Thermodevices (BEETIT)
- Electrofuels
- Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)
- Innovative Materials and Processes for Carbon Capture Technologies (IMPACCT)

ARPA-E accomplishes its mission by funding research and development at existing research laboratories, at national laboratories, universities, small businesses, large businesses, and non-profit organizations (See Figure 5).

ARPA-E, specifically through its Program Directors, manages a diverse portfolio of projects. The Program Directors are active participants in projects, working with project award recipients to help solve technical problems and to keep projects moving on their development track. When projects fail to meet technical milestones, the Program Directors carefully consider steps to improve performance, and may ultimately decide to recommend project termination and the redeployment of funds to those projects that show greater promise. The Director and Deputy Directors hold Program Directors accountable and review program direction regularly. Through these actions, ARPA-E acts as a responsible steward of the financial resources entrusted to it by taxpayers.

The following sections detail each program area, describing the national energy challenge that the program seeks to solve and the proposed transformational technologies that aim to do so. Following each program description are individual profiles of selected projects highlighted for their potential to provide meaningful impact. Each project within the ARPA-E program area is listed with key details and a brief description. (See Appendix B for a list of all 121 projects awarded funding by ARPA-E, organized by state of project headquarters location).

Figure 5 ARPA-E Projects by Lead Organization Type



ARPA-E Program: Open Funding Opportunity Announcement and Other Projects

ARPA-E's inaugural Funding Opportunity Announcement (FOA) was an open FOA and did not seek a specific technological goal. Rather, this FOA was open to all energy ideas and technologies and focused on applicants who already had well-formed research and development plans for potentially high-impact concepts or new technologies. Following a thorough review process, projects spanning ten topic areas were selected, based on their impact on ARPA-E's mission and opportunities for the U.S. to gain leadership, their innovative technical approaches and performance teams, and the pursuit of technologies that are underserved by other parts of DOE and the private sector. If successful, these technologies could be game-changing and launch new opportunities for American businesses and jobs.

Open Funding Opportunity Announcement and Other Projects Highlights:

- Direct Wafer: Enabling Terawatt Photovoltaics
- Wave Disk Engine
- Large-Scale Energy Reductions through Sensors, Feedback, & Information Technology

Open FOA Project Highlight: Direct Wafer: Enabling Terawatt Photovoltaics

Lead Organization	1366 Technologies, Inc. (Lexington, MA)
Award Amount	$4,000,000
Period of Funding	3/1/2010 to 8/31/2011
Primary Industry Area of Technology	Solar Photovoltaics / Thermal

The development team at 1366 Technologies, Inc., headquartered in Lexington, Massachusetts, is working on turning sunlight directly into low cost electricity through its innovative Direct Wafer technology. To date, the deployment of solar power has been limited by its high cost relative to other power sources. With ARPA-E's support, 1366 Technologies is developing a novel solar wafer manufacturing process that plucks wafers directly from molten silicon, dramatically cutting solar wafer cost. If successfully developed, 1366 estimates this technology could cut the cost of silicon wafers by 80 percent, cutting the cost of solar power in half from $0.15 per kilowatt hour today to less than $0.07 per kilowatt hour by 2020. Such a large drop in cost would bring solar power closer to parity with coal power, which currently generates 45 percent of U.S. electrical power. This improvement could increase U.S. solar electricity generation from 640 MW in 2009 to up to 500,000 MW in 2025—an amount of power generation capacity equal to almost half (45%) of what the total generation capacity in the U.S. was in 2009.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

Most of the solar panels bought and installed today are foreign-made, primarily from Asia. If this technology comes to fruition as planned, the United States could become a solar wafer exporter, capturing a large portion of the $10 billion per year silicon wafer market. Direct Wafer's projected 80 percent cost reductions, low capital requirements, and compatibility with the existing supply chain will facilitate rapid commercialization that could create more high paying U.S.-based jobs.

PROJECT NEWS

Since being awarded an ARPA-E grant of $4 million to develop its new wafer-making technology, 1366 Technologies has been able to increase its number of employees and complete a furnace that is now producing industry standard, full-size silicon wafers. Based on the success of its new wafer process, 1366 Technologies was able to raise more than $30 million in equity investments from new and existing investors as well as from two interested customers. Now the company is planning to break ground on a commercial manufacturing plant this year, near its R&D facilities in Massachusetts, to supply its first customers with 20 MW per year of wafers.

U.S. Department of Energy Secretary, Dr. Steven Chu, and ARPA-E Director, Dr. Arun Majumdar, visit 1366 Technologies to learn about the company's innovative Direct Wafer technology that could reduce the cost of solar panels by 80 percent. Source: Department of Energy

Open FOA Project Highlight: Wave Disc Engine

Lead Organization	Michigan State University (East Lansing, MI)
Award Amount	$2,540,631
Period of Funding	1/15/2010 to 1/14/2012
Primary Industry Area of Technology	Vehicle Technologies

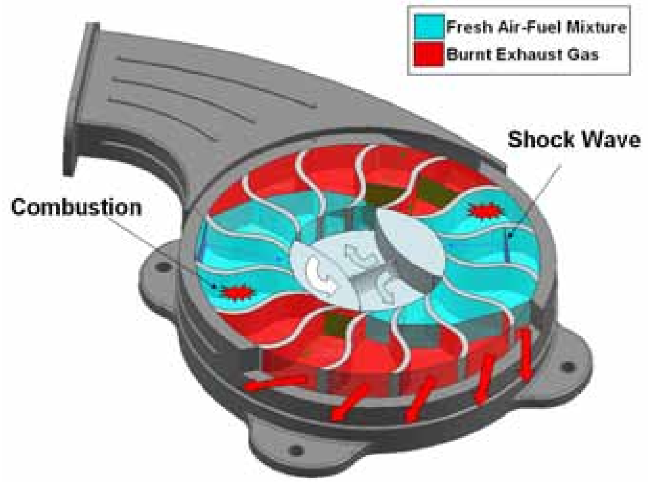
Researchers at Michigan State University are currently developing a novel engine for use in hybrid automobiles that if successful, will make better use of transportation fuel. According to the Department of Energy and the Environmental Protection Agency, nearly 85 percent of fuel is wasted by most vehicles on the road today, while only 15 percent of fuel goes toward the propulsion of the vehicle. MSU projects its innovative wave disk engine will enable a vehicle that would use 60 percent of its fuel for propulsion, significantly reducing the percentage of fuel that is wasted by conventional engines. The wave disk engine is compact in size, about the size of a cooking pot, yet it would replace nearly 1,000 pounds of engine, transmission, and cooling systems. MSU predicts its technology could enable hybrid vehicles to be about 30 percent lighter and 30 percent less expensive. Because it overcomes the cost and weight challenges and extends the range a vehicle could travel on a given amount of fuel, automobile companies will be able to use this new technology to produce lighter, more fuel-efficient hybrid vehicles. Michigan State's project was featured in a Popular Science article in February 2011.

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

The wave disk engine—an engine that is projected to be 30 percent lighter and 30 percent less expensive than those in plug-in hybrid vehicles—overcomes the high cost and weight limitations of current hybrid vehicles and improves the efficiency of the vehicle when using its gasoline engine. Additionally, this novel engine is scalable: it can be used in a vehicle as small as a motor scooter to one as large as a delivery truck.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

Success for the wave disk engine would radically improve the fuel consumption efficiency of vehicles. This technology could potentially reduce automobile CO_2 emissions by up to 90 percent and substantially decrease U.S. imports of fossil fuels from foreign sources.



Michigan State University's novel wave disk engine will make possible a lighter, less expensive hybrid vehicle with a driving range of over 500 miles. Source: MSU

Open FOA Project Highlight: Large-Scale Energy Reductions through Sensors, Feedback, and Information Technology

Lead Organization	Stanford University (Palo Alto, CA)
Award Amount	$5,006,011
Period of Funding	1/12/2010 to 4/15/2012
Primary Industry Area of Technology	Behavioral Science

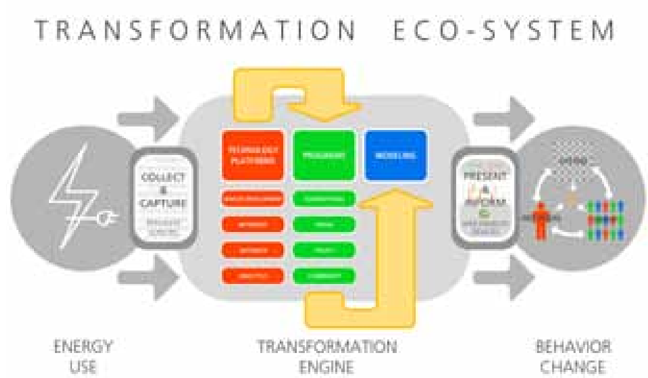
Stanford University is currently investigating how people make decisions about energy. Stanford's research combines behavioral approaches, product design, computation, and technology to encourage people to be more energy efficient at home, with a long term goal of reducing average residential energy use by over 20 percent. This interdisciplinary group of researchers and industry leaders will build and test system solutions at scale in the field, connecting people with smart meter and other sensor data via interactive media (for example, mobile devices and multiplayer games), engaging data visualizations, novel incentive systems, and innovative community programs (such as participatory programs with Girl Scouts of the USA), in order to encourage retrofits and the purchase and proper use of energy efficient technologies. The websites, databases, and other technology platforms developed in this project are utilized by the behavioral science research teams in their studies.

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

The potential of behavioral methods to reduce and shift energy use is being realized by Stanford investigators in several innovative ways. First, the initiative creates an information platform for testing new means to engage energy consumers and to collect data so that the effectiveness of energy programs can be evaluated quickly, easily, inexpensively, and at scale. This platform provides personalized diagnostics and recommendations, so that individuals are not left guessing which actions will make the biggest difference on their energy bill. The effectiveness of energy reduction recommendations is enhanced by incorporating media, incentive, and community programs developed from the learnings of multiple disciplines and utility, business, and non-profit partners. Second, the platform and large-scale data collection components of this initiative allow for improved demand-side response models that incorporate human action to inform future policy decisions. Third, the initiative develops hardware and an open and flexible home area network communications protocol to enable advances such as new services, tools, and software for energy management and conservation.

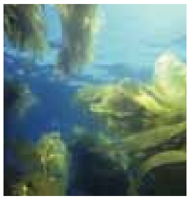
WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

This initiative aims to produce significant national energy savings and to improve the economy by increasing demand for energy efficient products and services. If successful, the Stanford team's research will result in publicly available websites, a collection of high-resolution data for disaggregation, and other technology platforms. Imagine a world where energy efficiency savings are realized with minimal effort and even with enthusiasm.



Stanford University's interdisciplinary approach to developing energy efficiency programs brings together researchers from communication, engineering, economics, psychology, medicine and computer science. Source: Stanford University

All Open Funding Opportunity Announcement and Other Projects by Technology Area



Biomass Energy

Biomass Energy refers to the solar energy stored in plants through the process of photosynthesis. Biomass energy projects focus on means to convert crops, along with plant waste from other industrial processes, into energy through chemical, biological, or thermal techniques that result in sustainable energy and fuels.

Catalytic Biocrude Production in a Novel, Short-contact Time Reactor

RTI International | Research Triangle Park, NC | $3,111,693

Transformational biofuels technologies like catalytic biomass pyrolysis have the potential to substantially enhance the economic and energy security of the U.S. by converting abundant domestic biomass resources into a hydrocarbon-rich pyrolysis liquid that can be upgraded into liquid transportation fuel. RTI is using ARPA-E funding to develop a unique process for bio-crude production. Working with a range of industry partners, RTI will focus on the development of a single-step catalytic biomass pyrolysis process with high carbon conversion efficiency to produce stable bio-crude with low oxygen content. This project is expected to yield a condensed hydrocarbon liquid (bio-crude) that can make use of the existing petroleum-refining infrastructure. If successful, this project could increase domestic production of renewable transportation fuels and reduce our nation's dependence upon foreign sources of fossil fuels and create new jobs.

Conditionally-Activated Enzymes Expressed in Cellulosic Energy Crops

Agrivida, Inc. | Medford, MA | $4,565,800

Agrivida is using ARPA-E funding to develop a new method for converting plant biomass into useful feedstock for the production of biofuels. To date, the use of plant biomass as feedstock for biofuel production has been limited by the difficulties inherent in degrading cell walls in plant cells. Agrivida aims to develop cell wall-degrading enzymes that can be produced at high concentration within plants. Once the crops are harvested, the engineered enzymes can be activated by adjusting the conditions of the biofuel production process. The activated enzymes would convert the plant cell walls into fermentable sugars that can be used to produce biofuels and other bio-products. If successful, this project could increase domestic production of renewable biofuels and reduce our nation's dependence upon foreign sources of fossil fuels.

High Biomass, Low Input Dedicated Energy Crops to Enable a Full-Scale Bioenergy Industry

Ceres, Inc. | Thousand Oaks, CA | $5,089,144

Using advanced plant breeding and biotechnology, Ceres is developing new varieties of energy grasses (specifically, switchgrass, miscanthus, and sorghum) for use as feedstock for the production of biofuels. These varieties will have greater yields than naturally-occurring grasses and require fewer agricultural inputs (e.g., nitrogen fertilizers). The ARPA-E funding will enable Ceres to test these varieties in the field and move closer to commercialization. Ceres projects that full-scale deployment of this technology could conserve 1.26 billion barrels of oil, 58 million tons of coal, 1.2 million tons of nitrogen fertilizer, 682 million tons of carbon dioxide, and 82 million pounds of nitrogen oxide emissions from 2020 to 2030. Indeed, the carbon sequestered in the roots of perennial plants like switchgrass and miscanthus has the potential to make these grasses carbon negative (i.e., they can sequester more carbon dioxide from the atmosphere than is released in the lifecycle of producing and burning the fuel derived from them). If successful, this project could increase domestic, renewable biofuel production, reduce our nation's dependence on foreign sources of fossil fuels, and generate new jobs.

MacroAlgae Butanol

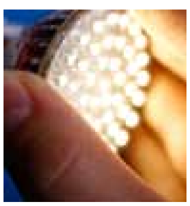
E.I. du Pont de Nemours and Company | Wilmington, DE | $8,884,698

With ARPA-E's financial support, E.I. du Pont de Nemours and Company (DuPont) is developing a commercially viable process for the production of an advanced biofuel, isobutanol, from seaweed. Using seaweed as a feedstock for the production of isobutanol has significant advantages, including reduced land use. Isobutanol has further advantages over alternative fuels like ethanol. For example, isobutanol is more comparable in performance to gasoline than ethanol, and can be blended in gasoline at higher levels than ethanol without changes to automobiles or the existing refinery and distribution infrastructure. DuPont aims to develop a microorganism to efficiently convert the sugars in seaweed into isobutanol. Dupont's projections show that Isobutanol could deliver a 90 percent reduction in greenhouse gas emissions compared to gasoline derived from petroleum. Seaweed-derived isobutanol has the potential to replace 6.8 billion barrels of gasoline per year in the U.S. alone. If successful, this project could increase domestic, renewable biofuel production, reduce our nation's dependence on foreign sources of fossil fuels, and decrease emissions of greenhouse gases.

Scaling and Commercialization of Algae Harvesting Technologies

Algaeventure Systems, Inc. | Marysville, OH | $5,992,676

With ARPA-E's financial support, Algaeventure Systems is developing a new and less expensive method for harvesting algae utilizing low energy surface chemistry properties in a mechanical-electrical device. Algae have a wide range of potential applications, such as in the production of food, feed, chemicals, plastics, and pharmaceuticals. More importantly, algae could be a rich source of feedstock for biofuel production. The principal obstacle to the use of algae in commercial products, including biofuels, is the high cost of harvesting and dewatering algae to extract the energy storage molecules (lipids) contained within the algae. To date, transforming algae into a dense sludge sufficient for lipid extraction has required a multistage, energy-inefficient process consuming 30 percent to 50 percent of the total cost of algae cultivation. Algaeventure Systems has designed and fabricated an innovative algae harvesting dewatering and drying system that is far more energy-efficient than existing techniques. If successful, this technology could dramatically reduce the energy cost necessary to harvest, dewater, and dry algae, and potentially, transform the economics of algae-based biofuel production and generate new jobs.



Building Efficiency

Building Efficiency projects focus on technologies that heat, power, and maintain buildings through sustainable and non-wasteful means.

Ammonothermal Bulk GaN Crystal Growth for Energy Efficient Lighting

Momentive Performance Materials, Inc. | Strongsville, OH | $4,519,259

Lighting consumes a significant percentage of total energy production. Momentive is developing gallium-nitride substrates for solid-state lighting that are more efficient at generating light and produce minimal waste heat. MPM will demonstrate a high-pressure, high-temperature process to grow single-crystal gallium nitride material with low defects that is inherently scalable to mass production. ARPA-E funding will enable Momentive to improve the technology and move closer to commercialization. If successful, this project will enable the deployment of low cost, high-efficiency solid-state lighting devices.

Large-Scale Energy Reductions through Sensors, Feedback, & Information Technology

Stanford University | Stanford, CA | $5,006,011

Stanford University is currently investigating how people make decisions about energy. Stanford's research combines behavioral approaches, product design, computation, and technology to encourage people to be more energy efficient at home, with a long term goal of reducing average residential energy use by over 20 percent. This interdisciplinary group of researchers and industry leaders will build and test system solutions at scale in the field, connecting people with smart meter and other sensor data via interactive media, engaging data visualizations, novel incentive systems, and innovative community programs, in order to encourage retrofits and the purchase and proper use of energy efficient technologies. If successful, the Stanford team's research will result in publicly available websites, a collection of high-resolution data for disaggregation, and other technology platforms.

Low Cost Electrochromic Film on Plastic for Net-Zero Energy Building

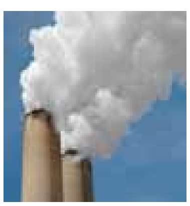
ITN Energy Systems, Inc. | Littleton, CO | $4,886,155

ITN Energy Systems is developing a film coating for windows that will significantly reduce heat and energy loss in all types of buildings–a solid-state electrochromic film on plastic substrates. The primary obstacle to the deployment of so-called "smart windows" is the significant cost of the energy-saving films. ARPA-E funding will be used to develop a new, cost-effective manufacturing process and intelligent, sensor-based process controls to monitor production quality. By adopting an innovative approach to manufacturing film coatings, ITN Energy Systems intends to lower their cost and enable their widespread adoption. If successful, this project could decrease energy use in buildings by up to 40 percent and significantly reduce pressure on utilities during periods of peak demand.

Novel Membrane-Based Dehumidification System that will Directly Manipulate Water Molecules via a Nano-Structured Polymer Membrane

Dais Analytic Corporation | Odessa, FL | $681,322

In warm and humid climates, the efficiency of air conditioning decreases significantly because moisture must be removed from the air. This project proposes to dehumidify moist air using a nano-structured solid polymer which is permeable to moisture but not permeable to air. The system creates a vacuum behind the membrane that pulls water vapor from air without changing its temperature. The vapor is expirated to the environment through a second set of membranes external to the controlled environment. This technology would enable higher efficiencies and significant cost savings in cooling technologies.



Carbon Capture

Carbon Capture and Sequestration technologies work to prevent the release of carbon dioxide into the atmosphere from traditional fossil fuel sources such as coal, natural gas, and petroleum. Projects funded by ARPA-E in this area seek to create new methods of carbon capture and greatly reduce the energy required to capture and sequester carbon dioxide.

Carbon Nanotube Membranes for Energy-Efficient Carbon Sequestration

Porifera, Inc. | Hayward, CA | $1,153,975

With ARPA-E's financial support, Porifera aims to develop high flux, high selectivity carbon nanotube membranes to efficiently separate carbon dioxide from industrial smokestack emissions. Presently, companies rely on chemical absorption to separate carbon dioxide from other emissions. However, chemical absorption is expensive and energy-intensive, and has an independent, negative impact on the environment. The goal of this project is to replace current chemical-based carbon dioxide separation technology with membrane-based technology. If this project is successful, it will result in carbon-dioxide separation membranes that deliver higher efficiency, cheaper sequestration, and lower energy consumption.

CO_2 Capture with Enzyme Synthetic Analogue

United Technologies Research Center | East Hartford, CT | $2,263,898

United Technologies Research Center (UTRC) is using ARPA-E funding to develop a new process for capturing the carbon dioxide emitted by coal-fired power plants. UTRC is focusing its research on a naturally-occurring enzyme that is used by nearly every organism on Earth to manage carbon dioxide levels. The naturally-occurring form would not survive within a smokestack environment, so UTRC seeks to develop a synthetic analogue of the enzyme that could be used to study aspects of its catalytic mechanism. The ultimate objective of this research is to create an enzyme analogue / polymer nano-composite thin-film structure that could act as a selective membrane to separate carbon dioxide from other gases in power plant smokestacks. The proposed technology may be easier to install and more reliable than existing technologies because it does not involve any moving parts or consumables. If successful, the proposed technology would allow coal-fired power plants to capture up to 90 percent of carbon at a significantly lower incremental cost.

Electric Field Swing Adsorption for Carbon Capture Applications

Lehigh University | Bethlehem, PA | $560,809

With ARPA-E's financial support, Lehigh University is developing a innovative approach to separate carbon dioxide from other gases in the smokestacks of coal-fired power plants. Lehigh University intends to use electric fields to reversibly and selectively enhance the affinity of certain high-surface-area, solid, absorbent materials for carbon dioxide. By flicking a switch, coal-fired power plants could control whether the materials adsorb carbon dioxide or release it for collection. ARPA-E funding will be used to develop appropriate materials and optimize the adsorption process. If successful, this technology would significantly reduce the time and energy required for carbon capture.

Energy Efficient Capture of CO_2 from Coal Flue Gas

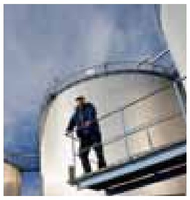
Nalco Company | Naperville, IL | $2,250,486

With ARPA-E's financial support, Nalco Company is developing a novel process to capture carbon in the smokestacks of coal-fired power plants. Nalco Company's electrochemical platform will rapidly capture carbon dioxide and desorb it at atmospheric pressure without heating, vacuum, or consumptive chemical usage. If successful, this technology will reduce the incremental carbon capture costs by up to 50 percent and make it more affordable for coal-fired power plants to clean their smokestack emissions.

Pilot-Scale Testing of Carbon Negative, Product Flexible Syngas Chemical Looping

The Ohio State University | Columbus, OH | $5,000,000

The Ohio State University (OSU) developed an innovative process—the Syngas Chemical Looping (SCL) process—for efficiently converting carbonaceous fuels such as coal and biomass into electricity, hydrogen, and/or liquid fuel with zero or negative net carbon dioxide emission. OSU will use ARPA-E funding to construct a 250 kWth pilot-scale plant to demonstrate the SCL process. A blend of biomass and coal will be converted to clean energy carriers such as hydrogen and electricity with 100 percent carbon dioxide capture. OSU is working with a wide range of companies to address all industrial concerns while preparing the technology for commercialization. Once commercialized, the process could be utilized to produce low cost electricity, hydrogen, and/or synthetic liquid fuel with zero or negative net carbon dioxide emission. If successful, the OSU team projects that this process would drastically reduce greenhouse gas emissions while promoting the efficient usage of indigenous energy sources such as coal and biomass.



Conventional Energy

Conventional Energy projects funded by ARPA-E seek to significantly increase the efficiency of traditional fossil fuel energy production and reduce waste generated from this use.

Upgrading Refinery Off-Gas to High-Octane Alkylate

Exelus, Inc. | Livingston, NJ | $1,000,000

Because of the sheer scale of oil refining in the U.S., even seemingly insignificant inefficiencies add up to massive losses of potential fuel. Among the most significant sources of wasted fuel is refinery off-gas. It is difficult and expensive to separate the useful elements in refinery off-gas, so refineries typically burn the refinery off-gas rather than putting it to productive use. With ARPA-E's financial support, Exelus Systems is developing a novel process for separating useful elements (e.g., olefin) from refinery off-gas. Exelus projects that its process process could allow 42 percent of refinery off-gas to be converted into approximately 46 million barrels of gasoline per year. Putting refinery off-gas to productive use would significantly reduce the emissions released by refineries burning refinery off-gas. If successful, this project will increase domestic production of gasoline and reduce carbon emissions.

Direct Solar Fuels

Direct solar fuel technologies utilize photosynthetic microorganisms to produce liquid fuels and fuel precursors directly from solar energy. In most cases, the microorganisms can work as biocatalysts to continuously produce fuels such as liquid hydrocarbons.

A Genetically Tractable Microalgal Platform for Advanced Biofuel Production

Iowa State University | Ames, IA | $4,416,852

With ARPA-E's financial support, Iowa State University (ISU) is modifying an aquatic microorganism, Chlamydomonas, to generate feedstock for the production of biofuels. Chlamydomonas is a versatile microorganism that can be easily managed and modified to assimilate carbon, generate energy-bearing molecules (lipids) from sunlight, and tolerate industrial-scale production. This project will generate new biofuel production capability, adaptable to a wide range of conditions and end products and with the transformational capability of genetically combining (i.e., breeding) a wide variety of desirable traits. If successful, this project will provide another renewable source of biofuels and reduce our nation's dependence on foreign sources of fossil fuels.

Affordable Energy from Water and Sunlight

Sun Catalytix Corporation | Cambridge, MA | $4,085,346

With ARPA-E's financial support, Sun Catalytix is developing a versatile, inexpensive, efficient, self-repairing, and scalable method for storage of renewable energy. Sun Catalytix will exploit a novel water oxidation catalyst that employs earth-abundant elements to generate hydrogen and oxygen from tap water or clean sea water. ARPA-E funding has enabled Sun Catalytix to move the novel catalyst technology from the academic laboratory to a commercial setting for practical application. Specifically, Sun Catalytix aims to design and develop a new class of electrolyzer and photoelectrochemical cell (PEC) devices, including an inexpensive 100 Watt electrolyzer and a direct solar-to-fuel PEC module. It is anticipated that both devices will be constructed from materials that support mass production, operate efficiently using readily-available water supplies, and serve as robust test-beds for innovative new products. If successful, this project will allow economical and distributed energy storage from renewable energy supply using water as a feedstock, and enable continuous power in off-grid locations at much lower cost than incumbent technologies.

Cyanobacteria Designed for Solar-Powered Highly Efficient Production of Biofuels

Arizona State University | Tempe, AZ | $5,205,706

With ARPA-E's financial support, Arizona State University (ASU) will use cyanobacteria (specifically, Synechocystis) to produce carbon-neutral, sustainable biofuels. Synechocystis grows on non-arable land, and therefore does not compete with food crops. ASU intends to modify Synechocystis to continuously convert sunlight and carbon dioxide to free fatty acids which will be harvested and converted into liquid jet fuel. If successful, this project could increase production of domestic renewable biofuels and reduce U.S. dependence on foreign sources of fossil fuels.

Shewanella as an Ideal Platform for Producing Hydrocarbon Biofuels

University of Minnesota | St. Paul, MN | $2,200,000

With ARPA-E's financial support, the University of Minnesota seeks to produce hydrocarbon fuels using the Shewanella bacteria. Hydrocarbon fuels have significant advantages over alternative fuels like ethanol. For example, hydrocarbon fuels, unlike ethanol, could make use of the U.S.' existing refining and distribution infrastructure. The University of Minnesota has already proven that naturally-occurring Shewanella bacteria produce hydrocarbons. The project aims to develop a novel bioreactor to couple a photosynthetic organism with Shewanella to convert carbon dioxide to hydrocarbons. This proposed research will also explore innovative bio-production methodologies to allow continuous harvesting of hydrocarbons, which would generate significant cost savings compared to traditional batch fermentation. The hydrocarbon feedstock generated by this novel approach will be chemically processed using knowledge obtained from a century of petroleum refining. If successful, this project could increase domestic production of renewable transportation fuels and reduce our Nation's dependence upon foreign sources of fossil fuels.

Energy Storage

Energy Storage technologies seek to revolutionize battery, capacitor, and other energy storage methods for significantly improved efficiency.

Electroville: High Amperage Energy Storage Device - Energy Storage for the Neighborhood

Massachusetts Institute of Technology | Cambridge, MA | $6,949,584

Providing uninterrupted, high quality electrical power for hospitals, manufacturing facilities, and residential communities is a problem across the Nation, especially as electrical grids become more reliant on renewable energy sources. One way to address this problem is to place large scale batteries near where power is used. However, batteries that meet the necessary performance requirements—long service lifetimes spanning thousands of cycles at deep depth of discharge (>80 percent), very high currents, and very low cost (less than $50 per kilowatt hour)–have yet to be invented. Researchers at Massachusetts Institute of Technology are working to develop the world's first all-liquid metal battery for community energy storage. Since the active materials in the battery are liquids, the battery size and capability can be scaled to the changing needs of the community where it is stored. The device will also use cheap and domestically abundant materials, meet the needed performance requirements, and greatly speed American ability to implement a more stable grid that can rely more on renewable energy.

High Energy Density Lithium Batteries

Envia Systems | Hayward, CA | $4,000,000

Envia Systems is using ARPA-E funding to develop lithium-ion batteries with extremely high energy density—over 400 Wh/kg versus the roughly 150 Wh/kg of current state-of-the-art batteries to enable long range electric vehicles. This project will entail the development of advanced high capacity silicon-carbon nano-composite anodes and complementary high capacity cathodes. In addition, Envia Systems will develop processes to scale the production of both anode and cathode materials to high volumes. Scaling of the materials will involve reproducibility of materials not only with high performance but also with high quality and consistency. If successful, this project will increase U.S. leadership in the field of advanced batteries, hasten the shift to hybrid/electric vehicles, and reduce U.S. dependence on foreign sources of fossil fuels.

Low Cost, High Energy and Power Density, Nanotube-Enhanced Ultracapacitors

FastCAP Systems Corporation | Boston, MA | $5,349,932

FastCAP Systems is using ARPA-E funding to develop a unique energy storage technology that would combine all of the advantages of ultracapacitors and batteries, without the disadvantages of either technology. Specifically, FastCAP Systems intends to produce an ultracapacitor made of carbon nanotubes: extremely small, high performance tubes of carbon that provide high energy density, high power, and extreme temperature reliability. In addition, the ultracapacitor will be safe from leaking and explosions. If successful, this project could greatly reduce the cost of hybrid/electric vehicles and increase their safety and reliability.

Planar Na-Beta Batteries for Renewable Integration and Grid Applications

EaglePicher Technologies, LLC | Joplin, MO | $7,200,000

Large-scale, low cost energy storage is necessary for widespread penetration of renewable energy and improved grid reliability. While high temperature sodium-beta batteries have long been a promising grid-scale energy storage technology, current sodium-beta battery technologies suffer from high cost and low reliability. Eagle Picher Technologies (EPT), in collaboration with the Pacific Northwest National Laboratory, is using ARPA-E funding to develop and demonstrate a completely new planar sodium-beta battery, a major departure from the current architecture based on highly expensive tubular designs. By using a novel and inexpensive stacked architecture, EPT aims to achieve dramatically improved performance at lower temperatures and lower cost. EPT's design will simplify the manufacturing process, and enable the production of scalable, modular batteries at half the cost of existing designs. The layered batteries will have increased active areas and decreased diffusion distances, which will increase energy density by 30 percent and power density by 100 percent. If successful, this project could create new jobs and allow large-scale battery storage on the electric grid to become a reality, making the grid more stable and easing the integration of renewable energy technologies onto the grid.

Silicon-Coated Nanofiber Paper as a Lithium-Ion Anode

Inorganic Specialists, Inc. | Miamisburg, OH | $1,999,447

Inorganic Specialists is developing a silicon-coated carbon nanofiber paper for use in lithium-ion batteries. This unique paper can store four times more capacity than existing anode technologies. This material is unique in that it simultaneously meets the criteria of breakthrough energy storage, low irreversible capacity, stable cycling, low cost, and viable manufacturability. ARPA-E funding will be used to develop manufacturing processes and equipment and to establish the feasibility of manufacturing the silicon-coated paper on an industrial scale. If successful, this project will accelerate the deployment of hybrid/electric vehicles and wind/solar power systems.

Sustainable, High-Energy Density, Low Cost Electrochemical Energy Storage—Metal-Air Ionic Liquid (MAIL) Batteries

Arizona State University | Tempe, AZ | $5,133,150

With ARPA-E's financial support, Arizona State University's Metal-Air Ionic Liquid (MAIL) battery program seeks to create a safe, ultra-high energy density, and low cost battery technology that incorporates earth-abundant materials. If successfully developed, the MAIL battery has the potential to increase the range of electric vehicles to distances approaching 1,000 miles and to dramatically decrease the cost of electric vehicles. To date, the use of advanced battery technologies has been limited by their low energy density, high cost, safety problems, and reliance on earth-rare materials from unreliable foreign sources. MAIL batteries will use domestically available earth-abundant materials to achieve lower cost and a more reliable supply of raw materials. Furthermore, MAIL batteries will have unparalleled safety because the primary chemicals will not be stored in the same space; hence, in the event of a crash involving a hybrid/ electric vehicle, there would be little or no risk of catastrophic energy release and fire. If successful, this project will enable the rapid and widespread deployment of long-range, low cost plug-in hybrid/electric vehicles and the use of the U.S. electric grid as the source of transport energy in place of imported fossil fuels.

Thermal Energy Storage With Supercritical Fluids

University of California, Los Angeles | Los Angeles, CA | $2,420,802

Two-tank molten salt is currently the preferred state-of-the-art thermal energy storage for solar thermal power plants. The UCLA-led team will develop a thermal energy storage system which will significantly reduce the cost and increase the volumetric and mass-based energy density. This team will develop and implement a supercritical fluid-based thermal energy storage system designed to operate both at moderate (100°C to 200°C) and high temperatures (300°C to 550°C) with a modular single-tank design. The high density of the supercritical state and the system's ability to provide high temperature storage enables high volumetric energy density. The team will identify and develop fluids with high specific storage capacity and design tanks to enable cost-effective, small footprint storage of solar thermal power. For high temperature storage, the volumetric energy density will potentially increase by over a factor of two when compared to two-tank molten salt systems, with a cost less than 70 percent of the molten salt system.

Renewable Power

Renewable Power projects focus on innovative technologies in several sustainable energy areas such as extremely efficient photovoltaic solar collectors, wind turbines, and geo-thermal energy.

1366 Direct Wafer: Enabling Terawatt Photovoltaics

1366 Technologies Inc. | Lexington, MA | $4,000,000

Crystalline silicon wafers are commonly used in photovoltaic cells to capture and convert sunlight to productive energy. To date, the use of photovoltaic cells has been limited by the high cost of manufacturing silicon wafers. With ARPA-E's financial support, 1366 Technologies is developing a novel wafer manufacturing process that plucks wafers directly from molten silicon. 1366 projects that its process could reduce wafer cost by 80 percent and cut the cost of installed photovoltaic systems in half. By dramatically lowering the cost of photovoltaic cells, this manufacturing process could enable the U.S. to add 500 GW in solar energy production and save approximately 500 million metric tons of annual carbon dioxide emissions by 2025. If successful, this project could increase domestic energy production and generate many new jobs in the solar photovoltaic industry.

Adaptive Turbine Blades: Blown Wing Technology for Low Cost Wind Power

Caitin, Inc. | Petaluma, CA | $3,000,000

With ARPA-E's financial support, Caitin will develop and construct a prototype "blown wing" (circulation control) wind turbine at the 100 kilowatt scale. "Blown wing" technology has the potential to introduce a radical simplification to the manufacturing and operation of wind turbines. Unlike a fixed airfoil, a "blown wing" can be dynamically adjusted to maximize power under a wide range of wind conditions. Unlike fixed airfoils, which must be laboriously manufactured to high precision, an effective blown wing can be generated from a slotted extruded pipe that can be domestically manufactured at a fraction of the cost. Blown wing technology has been demonstrated on fixed and rotary wing aircraft by the U.S. military, but no demonstration of blown wing technology has been attempted for wind turbines. If successful, this project could enable the economic proliferation of distributed, medium-scale wind turbine technology and potentially impact very large turbine design in sites throughout the U.S.

Airborne Wind Turbine

Makani Power, Inc. | Alameda, CA | $3,000,000

The Makani Airborne Wind Turbine converts wind energy into grid-quality, utility scale electricity using tethered, high-performance wings outfitted with turbines. Power is extracted from this motion by the wing-mounted turbines and transmitted to the ground through an electrically-conductive tether. However, because the wing is not constrained to rotate about a hub, it can sweep a much larger section of the sky than a conventional wind turbine and fly at a higher altitude where the wind is both stronger and more consistent. As a result, it can be deployed in parts of the country where traditional wind turbines cannot be deployed. Makani projects that its technology's advantages could result in a system that would deliver a capacity factor of 60 percent and with much lower overall mass. Makani will develop a prototype that will be used to validate the design and autonomous flight modes of the full scale system, which will reduce the cost of electricity compared to conventional horizontal axis wind turbines.

Breakthrough High Efficiency Shrouded Wind Turbine

FloDesign Wind Turbine Corp. | Wilbraham, MA | $8,325,400

With ARPA-E's financial support, FloDesign is developing a shrouded, axial-flow wind turbine capable of delivering significantly more energy per blade diameter than existing horizontal axis wind turbines and current duct augmented wind turbines. Inspired by the design of a jet engine, FloDesign's wind turbine is not only significantly cheaper to produce and operate than existing designs, but also has potentially wider application. The more compact design will enable the deployment of wind turbines in a wider range of locations, including urban environments. If successful, this project could facilitate the deployment of wind power in the U.S. and accelerate the shift to renewable energy sources.

Low Contact Drilling Technology to Enable Economical EGS Wells

Foro Energy, Inc. | Littleton, CO | $9,141,030

Geothermal energy is a potentially vast source of carbon-free electricity generation in the U.S. To date, the use of geothermal energy has been hindered by the difficulty in penetrating ultra-hard crystalline basement rocks. Conventional drill bits penetrate these rocks slowly and wear down quickly. As a result, drilling is slow and expensive. Foro Energy will use ARPA-E funding to develop a thermal-mechanical drilling technology that will increase drilling rates up to 10-fold relative to conventional drilling technologies. This increase in drilling efficiency will result in a significant reduction in drilling costs. If successful, this project could enable the widespread use of geothermal energy and accelerate the shift to renewable energy sources.

Optofluidic Solar Concentrators

Teledyne Scientific & Imaging, LLC | Thousand Oaks, CA | $1,000,272

Teledyne is developing a solar concentrator using an innovative optofluidic system based on electrowetting. Currently, tracking of solar radiation in concentrated photovoltaic systems is provided by mechanical means with multiple moving parts, which raises reliability concerns. These systems are also bulky. This project will develop an electrowetting-based dynamic liquid prism to track both the daily and seasonal changes of the Sun's orbit for concentrating photovoltaics (CPV). The electrowetting effect controls the contact angle of a liquid on a hydrophobic surface through the application of an electric field. This will reduce capital costs through increased operational efficiency by eliminating bulky mechanical tracking. Most importantly, the elimination of bulky tracking hardware and quiet operation will allow extensive residential deployment of concentrated solar power.

Vehicle Technologies

Vehicle Technologies funded through ARPA-E cover a range of groundbreaking technologies to advance efficiency in vehicles. This includes everything from creating new hybrid engine technologies to technologies that convert on-board waste-heat to electricity.

Advanced Power Semiconductor and Packaging

Delphi Automotive Systems, LLC | Kokomo, IN | $6,733,386

Delphi Automotive Systems is developing a novel electrical energy conversion module that will be 50 percent more efficient than existing silicon-based technologies. This module will consist of a high voltage semiconductor device combined with advanced connections and cooling to allow more electrical current to flow. This unique design will also reduce the module size, cost, and energy losses. Delphi Automotive Systems will use the ARPA-E funding to move the device closer to low cost, high-volume commercial production. If successful, this project will improve the energy efficiency and cost-effectiveness of hybrid/electric vehicles.

High Energy Permanent Magnets for Hybrid Vehicles and Alternative Energy

University of Delaware | Newark, DE | $4,475,417

High-energy permanent magnets are indispensable for many applications in the electric, electronic, automobile, communications, and information technologies industries. Currently, the demand for these magnets is even higher in the emerging markets of hybrid/electric vehicles, windmill power systems, power generation systems, and energy storage systems. The U.S. has lost its lead in this critical field of technology as producers have migrated to Asia. The University of Delaware's research and development will provide the fundamental innovations and breakthroughs that will help re-establish the U.S. as a leader in the science, technology, and commercialization of this essential class of materials. The goal of this project is to develop materials that will allow the U.S. to fabricate the next generation of permanent magnets with magnetic energy density (maximum energy product) two times higher than the current value of the strongest Nd-Fe-B magnets. If successful, this project will lead to lower-cost and more energy-efficient and power-dense magnets for deployment in a wide range of clean energy technologies.

Lightweight Thermal Energy Recovery (LighTER) System

General Motors Company | Warren, MI | $2,698,935

Each year, the U.S. loses an enormous amount of energy, equivalent to two trillion watts, to waste heat (i.e., heat generated by machines, electrical equipment, and industrial processes that is lost to the surrounding environment without being put to useful purpose). General Motors (GM) is using ARPA-E funding to develop a system for recovering waste heat in automobiles. By recovering the waste heat, GM will increase fuel economy. The new system will utilize shape memory alloys (SMAs), which are deformed by heat and return to their original form at cooler temperatures. GM will combine SMAs with mechanical designs to achieve a tenfold improvement in power generation compared to existing technologies. This project has potentially unlimited application. It is applicable to heat sources in transportation, homes, buildings and the natural world—anywhere a heat differential exists could be exploited to generate useful energy. If successful, this project could increase fuel efficiency by up to 10 percent and reduce annual fuel consumption in the U.S. by up to 380 million barrels.

Quaternary Phosphonium-Based Hydroxide Exchange Membranes

University of California, Riverside | Riverside, CA | $763,745

The University of California, Riverside (UC Riverside) is using ARPA-E funding to develop a new class of fuel cells. To date, the use of proton exchange membrane fuel cells (PEMFCs) has been hindered by their high cost, attributable to their use of costly materials—in particular platinum—as catalysts. UC Riverside will develop a new class of hydroxide exchange membranes (HEMs) that can eliminate the use of platinum in fuel cells and replace it with inexpensive metals such as nickel and silver, thus providing the breakthrough needed to make fuel cell technology economically viable. These fuel cells will have further benefits, such as high hydroxide conductivity, alkaline stability, and dimensional stability. Such fuel cells will also have immediate application in zero emission vehicles and solar and wind energy storage. If successful, this project could facilitate the use of fuel cells in automobiles and reduce U.S. demand for fossil fuels from foreign sources.

Transformational Nanostructured Permanent Magnets

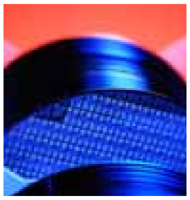
General Electric Company | Niskayuna, NY | $2,249,980

In this project, General Electric Global Research (GE) will develop cost-competitive, next-generation permanent magnets that will increase the efficiency and power density of electric machines while reducing raw material cost. These next-generation permanent magnets will have a magnetic energy product of at least 80 Megagauss Oersteds (MGOe) and 80% less rare-earth material content. To increase the magnet's energy product, GE will develop bulk proprietary nanostructured, consolidated, and fully dense microstructures and will demonstrate for the first time a bulk exchange-spring nanocomposite permanent magnet at the macroscale. These magnets will enable further market penetration of hybrid vehicles and wind turbine generators, while enhancing U.S. competitiveness in rare-earth mineral-based products.

Wave Disk Engine

Michigan State University | East Lansing, MI | $2,540,631

Researchers at Michigan State University are currently developing a novel engine for use in hybrid automobiles that will make better use of transportation fuel. According to the Department of Energy and Environmental Protection Agency, nearly 85 percent of fuel is wasted by most vehicles on the road today, while only 15 percent of fuel goes towards the propulsion of the vehicle. MSU projects that its novel wave disk engine will enable a vehicle that would use 60 percent of its fuel for propulsion, significantly reducing the percentage of fuel that is wasted. The wave disk engine is compact in size, yet it will replace nearly 1,000 pounds of engine, transmission, and cooling systems. MSU predicts that its technology will enable hybrid vehicles to be 30 percent lighter and 30 percent less expensive. Because it overcomes the cost and weight challenges and extends the range a vehicle could travel on a given amount of fuel, automobile companies will be able to use this new technology to produce lighter, more fuel-efficient hybrid vehicles. If successful, this project will significantly increase fuel consumption efficiency, reduce automobile emissions by up to 90 percent, substantially decrease U.S. imports of fossil fuels from foreign sources, and create new jobs.



Waste Heat Capture

Waste Heat Capture technologies capture thermal energy expelled by traditional industrial processes, such as coal smokestacks, and efficiently convert that heat into electricity.

Advanced Semiconductor Materials for High Efficiency Thermoelectric Devices

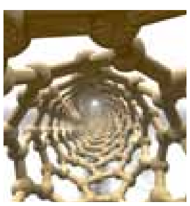
Phononic Devices, Inc. | Raleigh, NC | $3,000,000

To date, the U.S. generates most electricity by creating heat, whether it is through burning coal or splitting atoms. The heat, in turn, makes steam, which turns a turbine and makes electricity. This process is highly inefficient since approximately 60 percent of the heat is wasted. Phononic Devices intends to recapture this waste heat and convert it into usable electric power, or, depending on the source of the heat, to provide refrigeration and cooling. This 'thermoelectric' concept uses advanced semiconductor materials, similar to those found in microprocessors and solar cells, to manage heat by manipulating the direction of electrons at the nanoscale. Resembling computer chips, thermoelectric devices are quiet, and they have no moving parts or harmful emissions. Phononic Devices' projects that its design concepts will dramatically improve thermoelectric efficiency from less than 10 percent today to more than 30 percent, resulting in significant energy savings for power generation and cooling. If successful, this project would open new opportunities for domestic power generation from the large amounts of waste heat that exist in the U.S. energy economy.

Harvesting Low Quality Heat Using Economically Printed Flexible Nanostructured Stacked Thermoelectric Junctions

University of Illinois | Champaign, IL | $1,715,752

The University of Illinois is using ARPA-E funding to develop flexible, thermoelectric modules composed of silicon nanotubes and an economic and highly scalable approach to fabricate such modules. The modules' structural flexibility will enable their deployment in diverse settings with minimal customization of heat exchangers and use of real estate. For example, the modules could be put to immediate use in power plants, data centers, and automobiles. If successful, the thermoelectric modules could increase electricity production in the U.S. by up to 23 percent, without any accompanying increases in carbon and noise emissions.



Water

ARPA-E recognizes the interdependence of energy and water as crucial to our national and economic security. Broadly speaking, ARPA-E water technologies seek to reduce the water intensity of the electricity and fuel sectors and, reciprocally, to reduce the energy intensity of the water sector.

Carbon Nanotube Membrane Elements for Energy Efficient and Low Cost Reverse Osmosis

NanOasis Technologies, Inc. | Richmond, CA | $1,750,072

With ARPA-E's financial support, NanOasis will utilize carbon nanotubes to create industrially-scalable reverse osmosis (RO) membranes that could transform desalination and wastewater reuse and produce significant energy savings. Reverse osmosis is used to provide potable water by desalinating three main sources of input water: brackish inland waters, municipal wastewater, and seawater. NanOasis is developing RO membranes that it predicts will be ten times more permeable than existing membranes. These new membranes will not require any modifications to existing desalination plants. NanOasis' membranes will be packaged in the industry standard form-factor so they can be drop-in replacements in existing plants. If successful, NanOasis' membrane technology could reduce reverse osmosis energy consumption by 30 to 50 percent in existing desalination plants by the drop-in replacement of legacy RO membrane elements with NanOasis' ultra low pressure elements. In new desalination plants optimized around NanOasis' membrane technology, the total cost of water could be reduced by up to 40 percent by the combination of energy savings, membrane savings and smaller, less complex, lower cost facilities that could yield the same water output. If successful, NanOasis projects that this project could revolutionize the field of desalination and wastewater reuse and yield an estimated 290 trillion watt in energy savings over 10 years, corresponding to 177 million tons of carbon dioxide.

ARPA-E Program: Agile Delivery of Electrical Power Technology (ADEPT)

The Office of Electricity Delivery and Energy Reliability, part of the U.S. Department of Energy, estimates that within the next two decades, 80 percent of the electricity used in the U.S. will flow through power electronics. Power electronics modify the form of electrical energy (i.e., change its voltage, current or frequency) and can be found in applications as diverse as solid-state lighting, intelligent motors, electric vehicles, and a smarter electricity grid. Deploying advanced power electronics could reduce electricity consumption up to 30 percent, or 12 percent of total U.S. energy use. Innovations in power electronics could significantly reduce costs, which would promote U.S. businesses through technological leadership.

ARPA-E's ADEPT program is focused primarily on two areas: creating the world's first kilovolt-scale integrated circuits, and developing transistor switches operating at grid-level voltages that would exceed 13 kilovolts. Bringing the integrated circuit revolution to power applications can improve the performance of nearly every type of electrical component while simultaneously redefining the manufacturing platform for power systems. The development of grid-scale discrete transistors has the potential to create an actively controlled electric power grid where transformers can be reconfigured dynamically. The 14 projects that make up the ADEPT program strive to reinvent the basic building blocks of circuits from transistors, inductors, transformers to capacitors for a broad spectrum of power applications.

ADEPT Project Highlights:

- 15 kV Silicon Carbide (SiC) Insulated-Gate Bipolar Transistor (IGBT) Power Modules for Grid Scale Power Conversion
- High Performance Gallium Nitride (GaN) High Electron Mobility Transistor (HEMT) Modules For Agile Power Electronics

ADEPT Project Highlight: 15 kV Silicon Carbide (SiC) Insulated-Gate Bipolar Transistor (IGBT) Power Modules for Grid Scale Power Conversion

Lead Organization	Cree (Durham, NC)
Award Amount	$5,200,003
Period of Funding	8/20/2010 to 8/31/2013
Primary Industry Area of Technology	Semiconductors

Scientists at Cree, in Durham, North Carolina, are working to demonstrate the major energy efficiency advantages that advanced silicon carbide (SiC) power transistors will offer over existing technologies for power substations and other power grid applications. The transformers used for electrical power distribution today are very heavy—roughly 8,000 pounds. The advanced silicon carbide technologies that Cree is working to develop will allow for these heavy transformers to be replaced with much smaller high frequency transformers that are the size of a suitcase—at roughly one-eightieth the weight of today's transformers. These new, high voltage SiC power transistors could reduce electricity losses by 50 percent compared to existing power conversion technologies.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

The success of this project would mean that large, obtrusive and expensive power substations would be replaced by smaller and more efficient power substations. These high frequency power substations would modernize the electric power grid by being substantially more energy efficient.

PROJECT NEWS

As an industry leader in silicon carbide (SiC) power devices, Cree recently released a new SiC power transistor, the CMF20120D. Compared with other commercially available power transistors of similar ratings, this SiC power device has the lowest gate drive energy required for switching operation, and conduction losses that are minimized with a forward drop of less than 2 Volts at a current of 20 Amperes. While the ARPA-E project technology offers much higher voltage SiC power devices, the SiC power transistor released by Cree demonstrates the promise of SiC power technology for the future development of smaller, more efficient, utility power substations.

Cree is developing advanced silicon carbide power transistors that aim to reduce the energy lost in power conversion systems for the electric power grid by nearly half. Source: Cree, Inc.

ADEPT Project Highlight: High Performance Gallium Nitride (GaN) High Electron Mobility Transistor (HEMT) Modules For Agile Power Electronics

Lead Organization	Transphorm, Inc. (Goleta, CA)
Award Amount	$2,950,000
Period of Funding	9/1/2010 to 2/28/2013
Primary Industry Area of Technology	Semiconductors

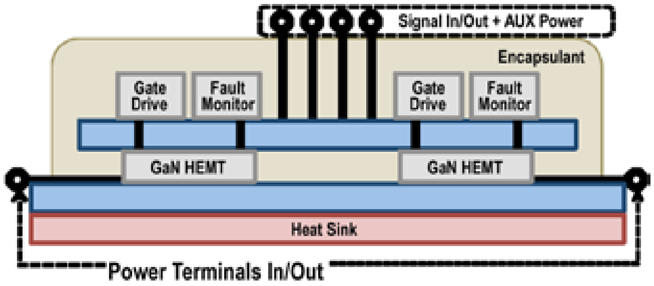
Transphorm, Inc., a California-based company, will dramatically reduce electric power waste by enabling the design and production of energy efficient motor drives, power supply, and photovoltaic inverters. The company's breakthrough technology arrives at a time when energy efficiency has emerged as a major driver of the clean energy economy. In this program, Transphorm is developing materials, devices, circuits and solutions to build the first power modules for inverters/converters operating at 1 megahertz (MHz), using kilovolt (kV) class gallium nitride (GaN) solid-state switches and rectifiers for kilowatt (kW) class motor drive applications. Today's high voltage power semiconductor devices do not reach speeds fast enough to realize low switching losses or create adequate driving waveforms for motor drives, degrading the performance of the overall drive and motor system. The high electron mobility GaN transistors being developed by Transphorm will result in faster and more efficient operation, enabled by lower levels of conduction and switching losses, as well as simpler and more compact systems.

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

Currently, gallium nitride transistors are very expensive to make on gallium nitride or silicon carbide substrates. The new technology being developed by Transphorm is intended to enable gallium nitride transistors on silicon substrates at lower manufacturing costs.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

Transphorm's transistors have the potential to revolutionize motor drives in the U.S. The more efficient and faster operating devices being developed by Transphorm will allow for better utilization, lower energy costs, and longer life for electric motors. These devices would also allow for more compact, variable speed motor drives that will enable new applications for electric motors. Deploying these advanced power semiconductor technologies could provide as much as a 25 to 30 percent reduction in energy consumption through increased efficiencies and would ensure U.S. leadership in the manufacturing of state-of-the-art motor drives. The superior characteristics of the GaN-based solutions also make this technology ideally suited to a variety of power conversion applications such as hybrid and electric vehicles and renewable energy (wind and solar) installations.



Transphorm, Inc., is developing high performance gallium nitride semiconductor devices that will allow for better utilization, lower energy costs, and longer life for electric motors.

All ADEPT Projects

15 kV SiC IGBT Power Modules for Grid Scale Power Conversion

Cree, Inc. | Durham, NC | $5,200,003

Scientists at Cree are working to demonstrate the major energy efficiency advantages that advanced silicon carbide (SiC) power transistors will offer over existing technologies for power substations and other power grid applications. The transformers used for electrical power distribution today are very heavy—roughly 8,000 pounds. The advanced silicon carbide technologies that Cree is working to develop will allow for these heavy transformers to be replaced with much smaller high frequency transformers that are the size of a suitcase—at roughly one-eightieth the weight of today's transformers. Cree predicts that these new, high voltage SiC power transistors could reduce electricity losses by 50 percent compared to existing power conversion technologies.

Advanced Technologies for Integrated Power Electronics

Massachusetts Institute of Technology | Cambridge, MA | $4,414,003

This project targets enabling improvements in the size, integration and performance of power electronics for high-efficiency solid-state lighting with a focus on circuits for interfacing with grid-scale voltages (greater than 100 volts) at power levels of 10 to 100 watts. Specifically it will develop Gallium Nitride on Silicon (GaN-on-Si) power devices, nano-structured magnetic materials and microfabricated magnetic components, and very-high-frequency power conversion circuits. Additional focus will be on the co-optimization of these novel elements to achieve high-performance.

Dynamic Control of Grid Assets Using Direct AC Converter Cells

Georgia Tech Research Corporation | Atlanta, GA | $998,619

With ARPA-E support, Georgia Tech is working to develop technology that could enable dramatic cost reductions in smart grid implementation and allow increased penetration of renewable energy resources by reducing transmission and distribution upgrade costs by up to 80 percent. A utility-scale, low cost Imputed DC Link Converter cell will be developed to realize direct and dynamic control of existing grid assets. The project will involve several developments—a new converter topology that achieves an AC/AC function using minimal number of switches, and the elimination of DC energy storage in the system.

Gallium-Nitride Switch Technology for Bi-directional Battery-to-Grid Charger Applications

HRL Laboratories, LLC | Malibu, CA | $5,058,752

The purpose of the project is to develop efficient, high power, and cost-effective power converters with application in the automotive sector. More specifically, it will utilize high voltage Gallium Nitride (GaN) on low cost silicon substrate switches operating at megahertz frequencies. The innovative design will result in a battery-to-grid bi-directional charger that enables efficient, cost effective power management focusing on grid-interactive distributed energy systems for the automotive sector.

High Performance GaN HEMT Modules for Agile Power Electronics

Transphorm, Inc. | Goleta, CA | $2,950,000

Transphorm aims to dramatically reduce electric power waste by enabling the design and production of energy efficient motor drives, power supply, and photovoltaic inverters. Transphorm is developing materials, devices, circuits and solutions to build the first power modules for inverters/converters operating at 1 megahertz (MHz), using kilovolt (kV) class gallium nitride (GaN) solid-state switches and rectifiers for kilowatt (kW) class motor drive applications. Today's high voltage power semiconductor devices do not reach speeds fast enough to realize low switching losses or create adequate driving waveforms for motor drives, degrading the performance of the overall drive and motor system. The high electron mobility GaN transistors being developed by Transphorm will result in faster and more efficient operation, enabled by lower levels of conduction and switching losses, as well as simpler and more compact systems. Deploying these advanced power semiconductor technologies could provide as much as a 25 to 30 percent reduction in energy consumption through increased efficiencies and would enable U.S. leadership in the manufacturing of state-of-the-art motor drives.

High Power Titanate Capacitor for Power Electronics

Case Western Reserve University | Cleveland, OH | $2,254,017

This project will develop novel capacitors for power electronics in the hybrid electric vehicle and consumer electronics markets. The capacitors will involve a new material, electrolytic titanate, and will include built-in spontaneous self-repair. Thin spine electrodes will enable low series resistance and inductance, as well as high power density. This will result in large improvements in energy density over state-of-the-art capacitors, as well as improvements in high frequency use, and price per kilowatt. The market for capacitors in power applications is $1.6 billion per year and represents a great opportunity.

Highly Laminated, High Saturation Flux Density Magnetic Cores for On-Chip Inductors in Power Converter Applications

Georgia Tech Research Corporation | Atlanta, GA | $1,016,017

Georgia Tech is working to greatly reduce the size and cost of, and to increase the efficiency of, laptop power supplies and other chargers and components used to power consumer electronics. It will do so through the development of low loss, high magnetic flux density, and metallic magnetic materials for single-chip power converters. New manufacturing technologies are employed to create stacked, extremely thin plate cores of iron alloys, forming them into inductors and transformers, and integrating them with specialized electronic components to make very small scale power converters.

Integrated Power Chip Converter for Solid State Lighting

Teledyne Scientific & Imaging, LLC | Thousand Oaks, CA | $3,439,494

Teledyne is developing a transformational 25 watt alternating current/direct current (AC/DC) power supply on a chip intended to impact the adoption of white solid-state lighting. The power supply will be the result of novel high energy density chip-scale capacitors; low loss, and low cost magnetics at megahertz frequencies; and chip-scale integration technologies with lower manufacturing and assembly costs. It will reduce the lifecycle cost of solid-state lighting and accelerate its adoption. Widespread use of solid-state lighting will save energy for lighting needs in the commercial, residential, infrastructure, and industrial sectors.

Isolated Converter with Integrated Passives and Low Material Stress

Virginia Polytechnic Institute and State University | Blacksburg, VA | $1,000,000

Virginia Tech is developing a monolithic power converter to be used in efficient power adapters for mobile applications, such as netbooks. The chip converter will include the integration of a transformer, ultra-high-density capacitors, and a nano-magnetic material dispensable with high precision by low cost inkjet printing. The magnetic structure, with a 3X improvement in energy storage, is introduced to keep the transformer volume at a minimum. The resulting highly efficient converters (greater than 90 percent) with high power density will reduce the 15 terawatt-hours of energy consumed by notebooks and netbooks annually.

Low Cost, Highly-Integrated Silicon Carbide (SiC) Multichip Power Modules (MCPMs) for Plug-in Hybrid

Arkansas Power Electronics International, Inc. | Fayetteville, AR | $3,914,527

Charging modules for plug-in hybrid electric vehicles (PHEVs) are grid-tie power electronics. As electric vehicles become more prevalent, higher power levels will become necessary to enable rapid battery charging. This project will develop and demonstrate a transformational, highly-efficient, ultra-compact, and low cost silicon carbide PHEV charger that will have a disruptive impact on electrical power conversion technology.

Metacapacitors

CUNY Energy Institute | New York, NY | $1,568,278

This project will develop nanoscale-engineered dielectrics for a new breed of capacitors that enable low cost, efficient inverters for small grid-tied photovoltaics and solid-state lighting. The thin film capacitor structures can be printed for high throughput, low cost microfabrication. Electronic switches and power electronic control integrated circuits are bonded onto and sealed into these capacitor films to form Metacapacitors. The resulting Metacapacitors are a high power density, low loss technology platform for load management and power conversion.

Monolithic Silicon Carbide Anode Switched Thyristor for Medium Voltage Power Conversion

GeneSic Semiconductor, Inc. | Dulles, VA | $2,530,958

GeneSiC Semiconductor is aiming to develop semiconductor materials, devices, and circuits to build 13,000 Volts and 50 Amperes silicon carbide solid state switches and rectifiers for utility power applications. Today's current power semiconductor devices do not reach voltages high enough to handle utility power distribution directly. Instead, current materials need to be stacked resulting in complicated circuits that require bulky insulation and cooling hardware. These silicon carbide devices will have vastly superior properties to conventional silicon, such as the ability to handle ten times the voltage-and one-hundred times the current at operating temperatures, making them ideally suited to high-power applications such as hybrid and electric vehicles, renewable energy (wind and solar) installations, and electrical grid control systems. These more efficient and controllable devices would not only allow for better utilization of transmission lines, resulting in higher efficiency of transmission and lower energy costs, but it would also reduce the frequency of power outages, which are very costly to the U.S. economy.

Nanostructured Scalable Thick-film Magnetics

General Electric Company | Niskayuna, NY | $949,533

Magnetic components often dominate the size, weight and cost of high-performance power converters for applications as diverse as solid-state lighting to grid-tied inverters for renewables. General Electric is working to develop a prototype power magnetic component with extremely high efficiency (97 percent) for kilowatt-level applications. It will develop a thick-film magnetic technology to enable advanced nanocomposite core materials for a new generation of compact, efficient, low cost power converters for photovoltaics. To develop the novel nanostructured, millimeter-scale magnetic materials, an advanced physical vapor deposition process will be used that is both scalable and low cost.

Power Supplies on a Chip (PSOC)

Virginia Polytechnic Institute and State University | Blacksburg, VA | $1,000,000

Virginia Tech is developing a technology to replace the current power management voltage regulators for powering the future generations of microprocessors, graphic cards and memory devices. A 3D integrated power supply on a chip (PSOC) will be developed using chip-scale integration of a new generation of Gallium nitride (GaN) on Silicon devices, with new high frequency soft magnetic material. By significantly reducing the size of magnetic components and eliminating most of the bulk capacitors, Virginia Tech expects its high density PSOC to free up to 90 percent of space on mother boards currently occupied by voltage regulators (25 percent of the motherboard).

ARPA-E Program: Batteries for Electrical Energy Storage in Transportation (BEEST)

The U.S. transportation sector is almost exclusively reliant upon petroleum-based fuels and this dependency comes with a large and increasing economic cost. The transport sector is a major contributor to U.S. reliance on foreign oil and air pollution. One way to reduce the impact of these factors is for more people to drive cars that use electricity instead of gasoline, where the electricity is stored in large on-board rechargeable batteries. A major roadblock to realizing this goal is the battery itself. Batteries for plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) are currently limited to a range of fewer than 100 miles for normal light duty vehicles. This limitation causes “range anxiety” among many Americans and will likely slow EV adoption due to a fear that EVs cannot take them everywhere they want, when they want.

The 10 projects that make up the BEEST program are developing batteries for PHEVs and EVs that can make a 300- to 500-mile-range electric car a reality. Successful development of these types of batteries will make PHEVs and EVs valuable to more people and could significantly reduce dependency on foreign oil for transportation. In this program, ARPA-E supports game-changing technologies that range from devices to double the minimum range of today’s EV cars, to high risk lithium-air batteries that could allow a car to travel up to 500-miles on a single charge.

BEEST Project Highlights:

- Semi-Solid Rechargeable Power Sources - Flexible, High Performance Storage for Vehicles at Ultra-Low Cost

- Development of Ultra-High Specific Energy Rechargeable Lithium-Air Batteries based on Protected Lithium Metal Electrodes

BEEST Project Highlight: Semi-Solid Rechargeable Power Sources: Flexible, High Performance Storage at Ultra-Low Cost

Lead Organization	24M Technologies, Inc. / Massachusetts Institute of Technology (Cambridge, Massachusetts)
Award Amount	$5,975,331
Period of Funding	9/1/2010 to 8/31/2013
Primary Industry Area of Technology	Energy Storage

Scientists at 24M, located in Cambridge, Massachusetts, are developing a new type of lithium-based battery for transportation and grid applications that stores large amounts of energy in a relatively small space by using a revolutionary flowable paste as the storage material. Current lithium-ion batteries, widely used in electric vehicles, cell phones, and laptop computers, are some of the most energy-dense batteries available, but their capacity is still limited. Recently released electric vehicles, for example, can travel only a fraction of the distance of a conventional automobile that runs on gasoline before needing to recharge. In addition, lithium-ion batteries are costly to produce: the battery pack in a current electric vehicle can cost over $15,000 to produce. Developed based on flow battery principles, 24M's lithium-based battery can hold far more energy than today's batteries by constantly flowing its specialized paste material through the battery's terminals. The battery's design also makes it easier to add capacity simply by adding more paste. Recharging the battery is done the same way that it is discharged: the paste is moved between the battery terminals while in "charge" mode.

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

With the specialized paste as the active material, this battery is able to access and store much more energy than today's lithium-ion batteries, while also costing less. Modeling and early laboratory results show that this new storage concept could produce dramatic increases in system-level energy density at costs below $100 per kilowatt hour. Additionally, this battery could add energy storage to the U.S. electricity grid and thereby help manage the uneven power output of renewable electricity sources.

PROJECT NEWS

After Yet-Ming Chiang, the MIT-based inventor behind the successful battery company A123 Systems (which had the largest IPO of 2009) received an ARPA-E grant to pursue this project, the team decided to form 24M as a startup around this technology, and a successful serial entrepreneur was brought in to run it. The new venture quickly attracted $10 million of Series A funding from two venture capital firms.

24M's lithium-based flow battery utilizes a revolutionary paste material that could drastically increase the driving range of electric vehicles. Source: 24M Technologies, Inc.

BEEST Project Highlight: Development of Ultra-High Specific Energy Rechargeable Lithium-Air Batteries based on Protected Lithium Metal Electrodes

Lead Organization	PolyPlus Battery Company (Berkeley, CA)
Award Amount	$4,996,311
Period of Funding	7/1/2010 to 6/30/2012
Primary Industry Area of Technology	Energy Storage

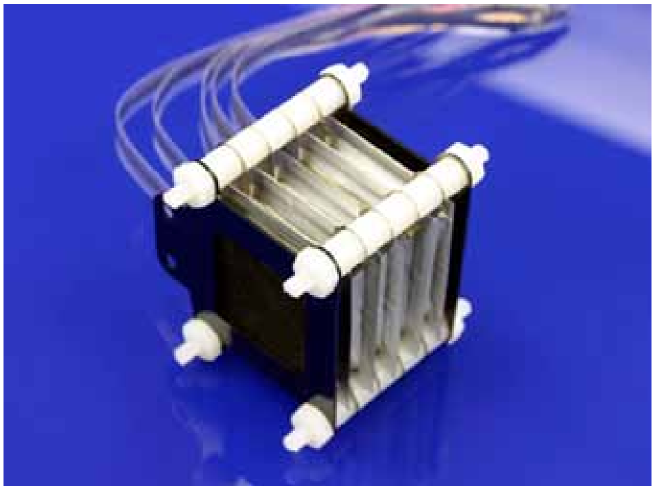
Imagine a world where electric cars could travel 500 miles on a single charge and go from zero to sixty miles per hour in less than five seconds. Imagine a world where no one would ever have to go to a gas station again, or ever go for an oil change again. The aim of this project is to make a prototype of the world's first truly rechargeable lithium-air battery that could make these types of electric cars a reality. Most present-day and near-term electric cars employ lithium-ion batteries to store energy—the same kind of batteries that are used in cell phones and laptop computers. These more traditional batteries are made up of solid powders divided by a separator film. The battery is charged and discharged by moving lithium from one side of the battery to the other, and back again. This self enclosed system is proven, but it requires so much material that it greatly limits the amount of energy that one battery can store. Lithium-air batteries, however, greatly decrease battery weight using air from the atmosphere as an active material in the battery, unlike in current batteries, where everything must be carried around in the battery itself.

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

With the success of this project, this rechargeable lithium-air battery would open the door to a completely new kind of electric vehicle (EV) battery. Compared to the best lithium-ion battery technology available today, PolyPlus estimates that its rechargeable lithium-air battery could store more than five times the amount of energy on a single charge. These cars could travel 500 miles on a single charge.

PROJECT NEWS

The concept of lithium-air batteries has been around for many years, but the ability to engineer the complex packaging and air-breathing components has kept it from being turned into a rechargeable system for decades. Within the last year however, new membrane and ceramic technologies in lithium-air battery construction have shown such great promise that a commercial product could potentially be introduced in 8 to 15 years.



PolyPlus is developing a lithium-air battery that could enable an electric car to travel 500 miles on a single charge. Source: PolyPlus Battery Company

All BEEST Projects

Development of High Energy Li-S Cells for Electric Vehicles

Sion Power Corporation | Tucson, AZ | $5,000,000

Sion Power Corporation will develop an ultra-high energy lithium-sulfur battery able to power electric vehicles more than 300 miles between charges, with an energy density of 500 watt hours per kilogram that is three times that of current lithium-ion batteries. While the high energy potential of lithium-sulfur is well known, Sion Power's proprietary strategy, focusing on a manufacturable approach to lithium anode protection and employing six different physical barrier layers, highly differentiates Sion's approach from all other lithium-sulfur efforts. These strategies directly address cycle life and safety while also allowing higher energies. If successful, this project will clearly assert U.S. technology and commercialization leadership in ultra-high energy batteries for electrified vehicles.

Development of Ultra-High Specific Energy Rechargeable Lithium-Air Batteries based on Protected Lithium Metal Electrodes

PolyPlus Battery Company | Berkeley, CA | $4,996,311

PolyPlus Battery Company and Corning, Inc., will work together to achieve transformational improvements in rechargeable lithium-air battery technology. PolyPlus's lithium-air batteries, based on proprietary protected lithium electrodes and Corning's specialization in glass, ceramics, and record of moving technology from laboratory to manufacturing, have great promise for advancing lithium-air technology, which has the potential to rival the energy density of gasoline. With a clear path to commercialization, this technology hopes to revolutionize lithium-air batteries for electric vehicle applications.

Enabling Novel Cathode Electrode Design with Integrated Separator and Manufacturing Toolset for High Energy Prismatic Li-Ion Battery Cells

Applied Materials, Inc. | Santa Clara, CA | $4,373,990

Applied Materials is leading an effort to develop ultra-high energy, low cost lithium-ion batteries enabled by disruptive new manufacturing processes. Applied Materials claims that its novel approach will focus on developing a high energy density, porosity-graded cathode on 3D current collectors, an integrated separator, and a suite of modular manufacturing processes that have the potential to transform lithium-ion battery manufacturing technology. These high energy cathodes will be incorporated with new high capacity anodes to demonstrate prototype manufacturing of high energy lithium-ion cells with energy density greater than 400 watt hours per kilogram and extremely low cost. If successful, this project could help establish U.S. leadership in the manufacturing of high energy, low cost advanced lithium-ion battery technology for electric vehicles.

High Performance Cathodes for Li-Air Battery

Missouri University of Science and Technology | Rolla, MO | $1,200,000

Researchers at the Missouri University of Science and Technology will lead a multi-disciplinary team to develop a disruptive new air cathode to enable the successful development of ultra-high energy lithium-air batteries. Lithium-air batteries have extremely high theoretical energy densities, approaching those of gasoline internal combustion engines due to the use of a high capacity lithium anode and oxygen from the air. However, existing lithium-air technologies have exhibited very low power, round trip efficiency, and cycle life due to severe performance limitations at the air cathode. In this project, researchers will seek to dramatically improve lithium-air cathode performance through the development of a new hierarchical electrode structure to enhance oxygen diffusion from the air and novel high performance bifunctional oxygen reduction and evolution catalysts. If successful, this project will re-establish U.S. technological leadership in this potentially disruptive battery technology for long range all-electric vehicles.

Low Cost Rechargeable Magnesium-Ion Batteries with High Energy Density

Pellion Technologies, Inc. | Cambridge, MA | $3,204,080

Pellion Technologies, an MIT spin-out company, will develop inexpensive high-energy-density rechargeable magnesium-ion batteries with the potential to disrupt current energy storage technologies for electric and hybrid-electric vehicles. To develop a game-changing magnesium-ion battery, Pellion will leverage high throughput computational materials design, coupled with accelerated materials synthesis and electrolyte optimization, to identify new high-energy-density magnesium cathode materials and compatible electrolyte chemistries. If successful, this project will develop the first commercial magnesium-ion battery and will establish U.S. technological leadership in this exciting new high energy battery chemistry for electrified vehicle applications.

High Energy Density Capacitors

Recapping, Inc. | Menlo Park, CA | $1,000,000

Researchers at Recapping and its partner Pennsylvania State University are developing a novel energy storage device based on a 3D nanocomposite structure with functional oxides that provide a very high effective capacitance. The basic fabrication of the dielectric materials and devices will utilize traditional multilayer ceramic fabrication methods that will provide a cost effective alternative to battery solutions, with added benefits of exploiting mechanisms that could maintain higher cycling and possibly deliver charge with high power density. This technology hopes to create a cyclable and economically competitive energy storage device that will catalyze new, related cleantech industries and contribute to the reduction of greenhouse gases and oil imports.

Semi-Solid Rechargeable Power Sources: Flexible, High Performance Storage at Ultra-Low Cost

24M Technologies, Inc. / Massachusetts Institute of Technology | Cambridge, MA | $5,975,331

Researchers at 24M, in collaboration with the Massachusetts Institute of Technology and Rutgers University, will seek to develop a revolutionary new electrical energy storage concept for transportation that combines the best attributes of rechargeable batteries and fuel cells. This technology incorporates semi-solid, high energy density, rechargeable, renewable and recyclable electrochemical fuel in a flow system that decouples power from stored energy. Early stage results suggest that high energy density and system costs less than $100 per kilowatt hour can be obtained, which would enable rapid widespread adoption of electric vehicles.

Solid-State All Inorganic Rechargeable Lithium Batteries

Planar Energy Devices, Inc.| Orlando, FL | $4,092,727

Planar Energy Devices seeks to develop an ultra-high energy, long cycle life all solid-state lithium-ion battery that can be manufactured using low cost non-vacuum fabrication techniques, targeting energy densities of 400 watt hours per kilogram and 1,080 watt hours per liter; system costs of $200 per kilowatt hour, and cycle life of 5,000. Planar Energy Devices will demonstrate pilot manufacturing of these disruptive new batteries using a low cost roll-to-roll process in ambient environment, all inorganic materials, and solid state electrolytes whose ionic conductivity is similar to existing liquid electrolytes. If successful, this project will establish the U.S. as a leader in advanced high energy battery technology and low cost manufacturing processes in batteries for electric vehicles.

The All-Electron Battery: A Quantum Leap Forward in Energy Storage

Stanford University | Stanford, CA | $1,501,742

Researchers at Stanford University seek to develop an "All-Electron Battery" that would enable a completely new class of electrical energy storage devices for electric vehicles. The All-Electron Battery has the potential to provide ultra-high energy and power densities, while enabling extremely high cycle life. This novel battery stores energy by moving electrons, rather than ions, and uses electron/hole redox instead of capacitive polarization of a double-layer. This technology uses a novel architecture that has potential for very high energy density because it decouples the two functions of capacitors: charge separation and breakdown strength. If successful, this project will develop a completely new paradigm in energy storage for electric vehicles that could revolutionize the electric vehicle industry.

Zinc Flow Air Battery (ZFAB), the Next Generation Energy Storage for Transportation

ReVolt Technology, LLC | Portland, OR | $5,000,335

ReVolt Technology seeks to develop a novel large format, high-energy zinc-air flow battery for long range Plug-In Hybrid and All Electric vehicles. This high energy battery concept is based upon a closed loop system in which the zinc (anode), suspended as slurry in a storage tank, is transported through air breathing reaction tubes (cathode) to facilitate the discharge and recharge of the battery. ReVolt's fundamental breakthroughs in air electrodes will enable a new class of high-energy rechargeable battery systems that combines key innovations from the fields of fuel cells and batteries.

ARPA-E Program: Building Energy Efficiency Through Innovative Thermodevices (BEETIT)

Residential and commercial buildings currently consume 40 percent of the primary energy consumed in the U.S., and they produce roughly 39 percent of total U.S. carbon dioxide emissions. Cooling is one of the major uses of energy in buildings, yet the basic approaches used for cooling have not changed in decades. New, more efficient methods of cooling represent a great opportunity to reduce energy consumption, especially from traditional refrigerants, from buildings.

The 16 projects funded through the BEET-IT program focus on developing new approaches and technologies for cooling equipment used in heating, ventilating, and air conditioning (HVAC) systems in our buildings, as well as in refrigeration. These projects aim to drastically improve energy efficiency in buildings at a cost comparable to current technologies. The technologies undergoing development in these projects are suitable for new building construction and can also be retrofitted into the existing cooling systems of legacy buildings, which will enable the U.S. to leverage its existing infrastructure.

BEETIT Project Highlights:

- Compact, Efficient Air Conditioning and Ionic Liquid-Based Refrigerants
- Non-Equilibrium Asymmetric Thermoelectric (NEAT) Devices

BEETIT Project Highlight: Compact, Efficient Air Conditioning and Ionic Liquid-Based Refrigerants

Lead Organization	University of Notre Dame (Notre Dame, Indiana)
Award Amount	$2,817,926
Period of Funding	10/1/2010 to 9/30/2013
Primary Industry Area of Technology	Building Efficiency

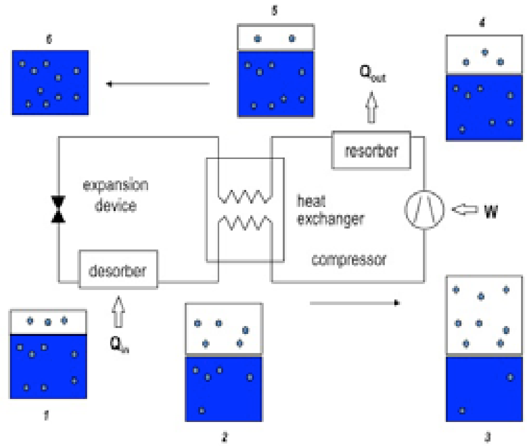
Researchers at the University of Notre Dame are working to develop a co-fluid vapor-compression cycle based on carbon dioxide and ionic liquids to potentially replace existing heating, ventilating, and air conditioning systems. Current vapor-compression refrigeration systems rely upon hydrofluorocarbon (HFC) refrigerants which have a high global warming potential (GWP), a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. Because the GWP of carbon dioxide is less than one-thousandth the GWP of HFCs, carbon dioxide becomes very attractive as a refrigerant. Carbon dioxide-based refrigeration systems, however, require pressure that is approximately 100 times higher than atmospheric pressure for operation, which has limited the feasible use of carbon dioxide as a refrigerant. Notre Dame's novel approach will allow the co-fluid vapor-compression system to run while reversibly absorbing the carbon dioxide, enabling the system to run with much lower pressure requirements. The project will extend system models to identify the characteristics of an optimal ionic liquid co-fluid, use atomistic simulation and experimentation to discover these fluids, and ultimately, demonstrate an operating carbon dioxide-ionic liquid system with efficiency as high as or better than that of existing ACs using HFC-410a refrigerants systems.

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

Using carbon dioxide as a refrigerant has not been commercially feasible due to its high pressure requirement, but using ionic liquids that can reversibly absorb carbon dioxide, this project will reduce the pressure requirements for carbon dioxide-based vapor-compression refrigeration systems. This technology could potentially replace current vapor-compression systems, which use hydrofluorocarbon refrigerants that have GWP values more than 1,000-fold that of carbon dioxide.

WHY THIS INNOVATION IS IMPORTANT TO THE UNITED STATES

The success of this project will lead to higher efficiencies, which translates into using less electricity and energy for air conditioning. This eco-friendly heating, ventilating, and air conditioning system will provide noticeable cost savings to consumers.

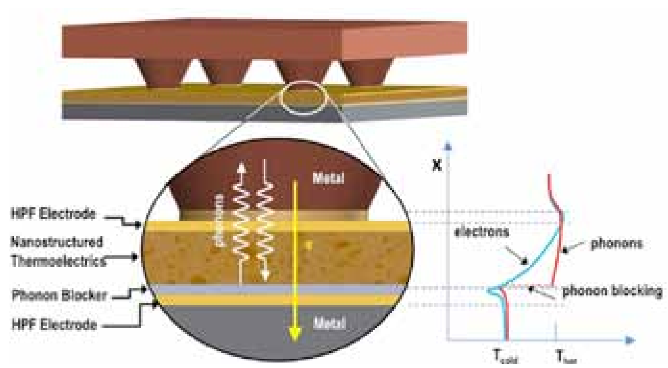


The University of Notre Dame is developing a co-fluid vapor-compression cycle using carbon dioxide and ionic liquid-based refrigerants to replace current vapor-compression systems that use hydrofluorocarbon refrigerants. Source: University of Notre Dame

BEETIT Project Highlight: Non-Equilibrium Asymmetric Thermoelectric (NEAT) Devices

Lead Organization	Sheetak, Inc. (Austin, TX)
Award Amount	$1,223,400
Period of Funding	9/1/2010 to 8/31/2012
Primary Industry Area of Technology	Building Efficiency

Traditional vapor-compression refrigeration systems, such as those used to produce cold air in building air conditioners and refrigerators, rely upon an evaporator, a condenser and expansion valve, and refrigerants with high global warming potential (GWP). The researchers at Sheetak, Inc., located in Austin, Texas, are developing a thermoelectric refrigeration system that produces cold air using less energy and without using fluids with GWP. Sheetak's Non-Equilibrium Asymmetric Thermoelectric (NEAT) refrigeration system aims to improve refrigeration engine efficiency by using thin films and non-equilibrium transport effects. Additionally, Sheetak's product will be light and will not involve moving components or special hardware. These improvements will lower the cost and increase the reliability of systems. Advances in efficiency of thermoelectric cooling engines resulting from NEAT will revolutionize air conditioning markets.



Sheetak's novel thermoelectric refrigeration system aims to improve the energy efficiency of cooling technologies and does not use refrigerants that are harmful to the environment. Source: Sheetak, Inc.

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

Sheetak plans to improve refrigeration engine efficiency to surpass that of current compressor systems using its understanding of thermoelectric behavior and electrical and thermal conductivity. Compared to a traditional compressor system with an evaporator, condenser and expansion valve, Sheetak claims that its product will be a complete system that produces cold air with decreased energy demands, resulting in a system that is less expensive to operate.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

The success of Sheetak's Non-Equilibrium Asymmetric Thermoelectric (NEAT) refrigeration system would mean reduced energy demands from refrigerators and air conditioners in our homes, office buildings, and cars.

All BEETIT Projects

A New Generation Solar and Waste Heat Powered Absorption Chiller

University of Florida | Gainesville, FL | $1,000,531

This project will develop a next-generation solar-powered absorption chiller that is an order of magnitude smaller than existing systems, and will be produced at a significantly reduced cost. The development of next-generation compact and inexpensive solar and waste heat-powered absorption refrigeration systems will substantially improve performance over the existing technology. Additionally, solar-powered absorption chillers will reduce heating, ventilating, and air conditioning energy consumption and carbon emission in a meaningful way. Absorption refrigeration systems fluids are considered not to have any global warming potential, another positive impact of the technology.

An Efficient, Green, Compact Cooling System Using Magnetic Refrigeration

Astronautics Corporation of America | Milwaukee, WI | $2,889,676

Astronautics Corporation of America proposes to construct a solid-state magnetic refrigeration cooling system to achieve significant energy efficiency and to reduce system operating costs compared to conventional vapor-compression systems. The magnetic refrigeration system will not use greenhouse or ozone-depleting gases and therefore has no global warming potential. Astronautics Corporation of Amercia will implement a theoretically modeled design using the rotating bed architecture. This is where a wheel of 16 beds rotates through a gap of a magnet assembly. Each bed will contain 14 layers of LaFeSiH in a connected-particle regenerator. Astronautics Corporation of America projects that the results of this project will reduce cooling power from 3.5 kilowatts to 1.0 kilowatts with minimal impact on efficiency. It will also achieve substantial system size reduction using magnetocaloric materials with larger entropy change and sharper transitions.

Compact, Efficient Air Conditioning with Ionic Liquid-Based Refrigerants

University of Notre Dame | Notre Dame, IN | $2,817,926

The global warming potential of current refrigerants is more than 1,000 times greater than the global warming potential of carbon dioxide. Consequently, this makes carbon dioxide very attractive as a referigerant. However, carbon dioxide-based refrigeration systems require approximately 100 times higher pressure than atmospheric pressure for operation. The team led by University of Notre Dame will develop a co-fluid vapor compression cycle based on carbon dioxide and ionic liquids. This will facilitate the running of the carbon dioxide vapor compression system with a co-fluid that reversibly absorbs the carbon dioxide, thus greatly reducing the pressure requirements. The project will extend system models to identify the characteristics of an optimal ionic liquid co-fluid, use atomistic simulation and experimentation to discover these fluids, and ultimately, demonstrate an operating carbon dioxide-ionic liquid system with efficiency well beyond that of existing ACs using HFC-410a refrigerants systems.

Compact MEMS Electrocaloric Cooling Module

University of California, Los Angeles | Los Angeles, CA | $520,547

UCLA will develop a novel solid-state cooling technology to translate a recent scientific discovery of the enhanced electrocaloric effect into commercially viable compact cooling systems. UCLA will utilize micro/nano-scale manufacturing technologies to extend the performance and reliability of the cooling module, develop physical models to identify optimal designs of key components, exploit nanoscale phenomena to develop materials with tunable thermal and thermomechanical properties, develop reliable thermal interfaces to achieve cooling power densities, and use precision micro-fabrication technologies to enable design and manufacture of reliable mechanical components. This technology seeks to develop highly efficient cooling technology that will reduce energy consumption in building space cooling, and will avoid the use of refrigerants.

High Efficiency Adsorption Chilling Using Novel Metal Organic Heat Carriers

Pacific Northwest National Laboratory | Richland, WA | $2,513,827

A team of researchers a Pacific Northwest National Laboratory will develop a new class of adsorption chiller that takes advantage of the tunable binding energy available with metal organic heat carrier sorbents, a nanoporous structured material, and select refrigerants to achieve high efficiency in commercial heating, ventilation, air conditioning and refrigeration systems. This project will develop a 5-ton minimum cooling capacity prototype unit designed, assembled and tested with a target coefficient of performance of 1.5 or higher: a breakthrough in adsorption chiller technology performance.

High Efficiency, On-line Membrane Air Dehumidifier Enabling Sensible Cooling for Warm and Humid Climates

Advance Materials Products, Inc. | Hudson, OH | $3,269,965

In warm and humid climates efficiency of air conditioning decreases significantly due to energy used to remove the moisture from the air. This ADMA-led team will develop an air cooling and dehumidification metal foil-like membrane sheet that can sieve out water molecules from the humid air stream that flows over it. Pacific Northwest National Laboratory will make this membrane by deposition of a very thin layer of a special class of ceramic materials, known as a molecule sieve, on the surface of a porous metal sheet about the thickness of a piece of paper. The membrane allows water vapor permeation at very high flux while blocking air molecules. ADMA will use its expertise to develop roll-to-roll manufacturing processes to fabricate the product at a low cost. If successful, this technology will significantly reduce energy consumption for air cooling in hot and humid climates and reduce future carbon dioxide emission growth from the heating, ventilating, and air conditioning sector.

Innovative Building-Integrated Ventilation Enthalpy Recovery

Architectural Applications | Portland, OR | $458,265

Architectural Applications and team members will develop a membrane-based enthalpy exchanger that captures the cooling and dehumidifying benefit from building-exhausted air and recycles it to partially condition incoming fresh air. Contrary to conventional enthalphy recovery systems, this system is located within the depths of the building enclosure and can have a large surface area, with very slow air flow over it, resulting in high efficiency enthalpy recovery with little added fan power. Its integration into the wall will reduce demand on and size of the building air conditioning equipment. It will also work well for existing building renovations. The system promises a coefficient of performance increase of 25 to 40 percent compared to conventional air conditioning systems.

Modular Thermal Hub for Building, Cooling, Heating and Water Heating

Georgia Tech Research Corporation | Atlanta, GA | $2,399,765

A team of researchers at Georgia Tech will develop a thermally-activated hub for modular, scalable, distributed cooling and heating in buildings that can run on thermal energy from combustion, low-grade waste heat or solar energy. This project leverages several-fold enhancements in coupled heat and mass transfer made possible through microscale passages. Cooling capacities ranging from hundreds to tens of thousands of watts are possible by scaling-up component geometry. The mass-producible miniaturized systems can be packed as monolithic full-system packages or discrete, distributed hydronically-coupled components for both residential and commercial building applications. The reversible operation enables space cooling and heating, coupled with water heating, to yield equivalent electrical energy-based coefficient of performances of 2.5 to 8.3, equating to a primary energy use reduction of 51 percent while using fluids with zero global warming potential.

Nano-Engineered Porous Hollow Fiber Membrane-Based Air Conditioning System

United Technologies Research Center | East Hartford, CT | $3,098,883

United Technologies Research Center and Pall Corporation will develop and demonstrate an air conditioning system optimized for use in warm and humid climates with an efficiency of at least 50 percent greater than conventional air conditioning units. UTRC will integrate a liquid desiccant and a vapor compression cycle to overcome current barriers of liquid desiccant systems: corrosion and carryover. The concept is projected to obtain a primary coefficient of performance of 1.13, compared to 0.75 for conventional air conditioning systems at the ARPA-E cost target of $1,500 per ton for new systems and $1,000 per ton for retrofits. The project includes identifying and characterizing membrane materials and structures, designing the heat and mass transfer modules required to provide heat and humidity removal, and developing the components and controls required for successful integration.

Non-Equilibrium Asymmetric Thermoelectric (NEAT) Devices

Sheetak, Inc. | Austin, TX | $1,223,400

Sheetak proposes to develop a new thermoelectric material system known as Non-Equilibrium Asymmetric Thermoelectric (NEAT), which can achieve high performance in solid-state refrigeration compressors. Sheetak plans to improve refrigeration engine efficiency to surpass that of current compressor systems using its understanding of thermoelectric behavior, and electrical and thermal conductivity. Compared to a traditional compressor system with an evaporator, condenser and expansion valve, Sheetak's product will be a complete system that produces cold air without using fluids with global warming potential, and with decreased energy demands.

One-Ton Thermoacoustic Air Conditioner

Pennsylvania State University | State College, PA | $2,908,239

This team led by Penn State proposes to scale-up an existing thermoacoustic-Stirling chiller system to produce a 1-ton air conditioning unit that uses high-amplitude sound and helium gas to recycle acoustical power for cooling. The project will scale up an ice cream chiller built for Ben & Jerry's that combined the acoustic power produced by high-efficiency moving-magnet linear motor with recycled power to produce useful cooling in a "bellows bounce" thermoacoustic chiller. This project will not use exotic materials that increase cost or reciprocating seals that limit service life.

Phononic Heat Pump

Material Methods, LLC | Irvine, CA | $399,800

A research team at Material Methods, will demonstrate a refrigerator that pumps heat using sound waves. Low cost and high reliability result from high thermal efficiency and mechanical simplicity with no linkages, no exotic materials, and simple construction. The working fluid is environmentally safe and friendly.

Stirling Air Conditioner (StAC) for Compact Cooling

Infinia Corporation | Kennewick, WA | $3,000,617

Infinia proposes to develop and demonstrate a prototype Stirling Air Conditioner (StAC) that combines the Stirling cycle with innovative heat transfer coupling to produce improvements in compact cooling. This project will use no greenhouse gases, can achieve a system coefficient of performance greater than 4, and is cost effectively mass-producible with a system lifetime exceeding that of traditional vapor-compression systems. Other benefits include the ability to operate over a wide range of environmental temperatures and humidity conditions with high efficiency, the ability to modulate output with variable speed fans, and the ability to scale to various sizes to meet market needs.

The Absorption-Osmosis Cooling Cycle

Battelle Memorial Institute | Columbus, OH | $400,000

More than 90 percent of cooling is provided by vapor compression-based systems which use mechanical compressors. Battelle Memorial Institute proposes to demonstrate cascade reverse osmosis technology to separate refrigerant water from an absorbing salt solution for re-use in the cooling cycle for refrigeration. This project will replace compression of refrigerant vapor and/or thermal distillation of refrigerant in a traditional refrigeration absorption cycle with a more efficient liquid pumping and membrane separation process using currently-available reverse-osmosis membranes. Battelle's modeling has shown that the absorption osmosis cycle can be 86 percent more efficient than a vapor-compression cycle, which will result in energy and cost savings. Cascade RO can also have substantial impact in water processing as a stand-alone technology because it expands the applicability of reverse osmosis beyond its current use in purifying water.

Thermoelastic Cooling

University of Maryland | College Park, MD | $500,001

A team led by University of Maryland proposes to demonstrate a 0.01-ton prototype for cooling based on thermoelastic shape memory alloys with the goal of establishing the commercial viability of thermoelastic cooling. Thermoelastic cooling systems can be 175 percent more efficient than conventional vapor compression technology, currently used for 90 percent of U.S. space cooling. Replacing vapor compression technology with thermoelastic cooling will reduce U.S. annual primary electricity consumption by up to 2.2. quads per year, the equivalent of 250 metric tons per year of carbon dioxide emissions. Thermoelastic cooling refrigerant is a solid state technology, which eliminates the need for high global warming potential refrigerants and requires a smaller operational footprint.

Water-Based HVAC System

United Technologies Research Center | East Hartford, CT | $2,855,795

United Technologies Research Center proposes to develop a 1-ton capacity air conditioning system with a coefficient of performance of 4 or greater, with water as a refrigerant and utilizing a novel type of supersonic compression that enables high-compression ratios in a single stage, thus, enabling lower cost than existing designs. Several heat exchanger options will be explored including direct contact with secondary circulating loops. Water is a natural refrigerant and can potentially reduce the use of synthetic refrigerants that have a higher global warming potential.

ARPA-E Program: Electrofuels

Liquid fuels are a ubiquitous component of the Nation's energy landscape. According to the U.S. Energy Information Administration, the U.S. will continue to rely on liquid fuels at a constant level for the next 20 years, even with the increased deployment of plug-in hybrids and electric vehicles. The U.S. transportation sector is almost exclusively reliant upon petroleum-derived liquid fuels, and this dependency comes with a large and increasing economic cost.

Domestically-produced biofuels increase the Nation's energy security, but there remains considerable need for next-generation renewable fuels that can be integrated into the Nation's current fuel refining and distribution infrastructure. Most of the methods for producing biofuels that are currently under development involve converting biomass or waste, or directly producing fuels from sunlight and carbon dioxide, but overall efficiencies from these approaches remain low. The 13 projects that comprise the Electrofuels program intend to explore new paradigms for the production of renewable liquid fuels that are compatible with today's infrastructure—using microorganisms to harness chemical or electrical energy to convert carbon dioxide into liquid fuels, without using petroleum or biomass.

Electrofuels Project Highlights:

- Biofuels from Carbon Dioxide Using Ammonia-Oxidizing Bacteria in a Reverse Microbial Fuel Cell
- Novel Biological Conversion of Hydrogen and Carbon Dioxide Directly into Biodiesel

Electrofuels Project Highlight: Biofuels from Carbon Dioxide Using Ammonia-Oxidizing Bacteria in a Reverse Microbial Fuel Cell

Lead Organization	Columbia University (New York, NY)
Award Amount	$543,394
Period of Funding	7/1/2010 to 6/30/2012
Primary Industry Area of Technology	Biofuels

Columbia University is using the bacteria, Nitrosomonas europaea, to optimize the conversion of carbon dioxide and ammonia into a liquid transportation fuel. The biofuel production process is powered by biological extraction of energy from ammonia, an abundant and affordable chemical, which can be regenerated by renewable electricity and fed back into the biofuel production system when depleted by the bacteria. This unique technical approach is expected to be more efficient than current photosynthetic-dependent biofuel production systems and will not require large acreage. With the success of this project, biofuel production will no longer be limited to particular geographic areas and can be more distributed throughout the country. The technology being developed will produce isobutanol, an alcohol with performance characteristics more similar to gasoline than is ethanol, which could accelerate the deployment of this fuel into our current infrastructure.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

Scientists and engineers have demonstrated that biofuels from various sources contribute fewer greenhouse gases to the atmosphere than traditional petroleum-based fuels. In the process of producing eco-friendly biofuel, the envisioned technology essentially recycles carbon dioxide from fuel combustion back into the fuel. ARPA-E's investment in this particular technology is a step towards securing next-generation biofuel intellectual property within the U.S., which can be used to develop new industry in the U.S. and increase exports to other nations for deployment globally.

PROJECT NEWS

The Columbia team has assessed, and has been encouraged by, data suggesting that the Nitrosomonas europaea can convert ammonia to energy at near 100 percent efficiency.

Columbia University is using bacteria to convert ammonia into liquid transportation fuel. Source: Eileen Barroso and Columbia University

Electrofuels Project Highlight: Novel Biological Conversion of Hydrogen and Carbon Dioxide Directly into Biodiesel

Lead Organization	OPX Biotechnologies, Inc. (Boulder, CO)
Award Amount	$5,997,490
Period of Funding	7/12/2010 to 7/11/2013
Primary Industry Area of Technology	Biofuels

OPX Biotechnologies, Inc., headquartered in Boulder, Colorado, is working to develop a biological approach to sustainable fuel production—efficiently extracting energy from hydrogen gas to convert carbon dioxide into liquid transportation fuel at a cost of less than $2.50 per gallon. This technology will not rely upon photosynthesis, as most biofuels produced today. This means that the team's novel approach will bypass the many inefficiencies of using photosynthesis and will not require the accumulation of plant material, sugar production, vegetable oil, or large amounts of land or water to collect energy from sunlight. The project will combine OPX Biotechnologies' proprietary genomics technology with expertise in biological hydrogen utilization from the National Renewable Energy Laboratory.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

If successful, this project would result in the deployment of billions of gallons of new biofuel production capacity that does not compete for land or commodity crops for food and animal feed. The technology would enable biofuel production over a much broader geographic area not constrained by resources such as soil, sun, and water. Future generations will be able to fuel vehicles with sustainable and uniquely American-made fuels, produced by biology rather than fossil fuels.

PROJECTS NEWS

The OPX Biotechnologies team has successfully optimized fermentation conditions for the bacteria and has achieved cell concentrations at targets needed for a commercial process. Key progress has been made towards engineering the bacteria to produce biodiesel from hydrogen and carbon dioxide.

OPX Biotechnologies' novel biological approach to biofuel production utilizes hydrogen gas to convert carbon dioxide into biodiesel. Source: OPX Biotechnologies, Inc.

All Electrofuels Projects

Bioconversion of Carbon Dioxide to Biofuels by Facultatively Autotrophic Hydrogen Bacteria

The Ohio State University | Columbus, OH | $3,977,349

The Ohio State University proposes a technology for the efficient bioconversion of carbon dioxide into an infrastructure-compatible liquid biofuel—butanol—without using photosynthesis. The project includes genetic modifications of bacteria that metabolize carbon dioxide, oxygen, and hydrogen to produce butanol; development of an industrially scalable bioreactor system; and a new approach to recovery of butanol from the bioreactor. The team anticipates at least a two-fold productivity improvement over current levels and a cost that can be competitive with gasoline. The project also includes a proprietary process to convert waste biomass into carbon dioxide and hydrogen to feed the bioreactor, allowing butanol production from waste feedstocks.

Biofuels from CO_2 Using Ammonia-Oxidizing Bacteria in a Reverse Microbial Fuel Cell

Columbia University | New York, NY | $543,394

This Columbia University project team will use the chemolithoautotrophic ammonia-oxidizing bacteria Nitrosomonas europaea to produce isobutanol from carbon dioxide. The team will genetically engineer the microorganism to demonstrate that they can efficiently use ammonia that can be generated electrochemically from nitrite, or supplied from waste water streams, to fix carbon dioxide.

Bioprocess and Microbe Engineering for Total Carbon Utilization in Biofuel Production

Massachusetts Institute of Technology | Cambridge, MA | $3,863,563

This project will develop a process to combine an anaerobic carbon dioxide-fixing microbe in one stage with an aerobic oil-producing microbe in a second stage. From hydrogen and carbon dioxide, the anaerobic organism would produce an organic compound, such as acetate, that could be used by the aerobic microbe for growth and oil production at close-to-theoretical yields. The net effect would be the production of oil for biodiesel from carbon dioxide and hydrogen or electricity. The aerobic microbe has been engineered at MIT and is capable of converting a variety of organic compounds into oil, from which biodiesel may be produced. The project aims to dramatically increase volumetric productivity (for acetate production) using targeted metabolic engineering and integrated bioprocess development.

Development of an Integrated Microbial-ElectroCatalytic (MEC) System for Liquid Biofuel Production from CO_2

Lawrence Berkeley National Laboratory | Berkeley, CA | $3,439,507

A team at Lawrence Berkeley National Laboratory will develop a novel, combined microbial and electrochemical catalytic system to convert hydrogen and carbon dioxide into energy-dense biofuels. A common soil bacterium, Ralstonia eutropha, will be genetically modified to produce biofuels including butanol and alkenes, which can serve as replacements for petroleum-derived fuels. A novel metal complex for hydrogen production will be coupled to the bacteria. The project also aims to develop a chemical method to transform butanol into jet fuel.

Development of Rhodobacter as a Versatile Platform for Fuels Production

Pennsylvania State University | University Park, PA | $1,500,000

This project will produce an organism capable of using electricity to ultimately produce gasoline from carbon dioxide. The Penn State University team will engineer hydrocarbon biosynthesis genes from an oil producing algae into a hydrogen-consuming bacteria for efficient biofuel production. The project also includes innovative concepts for engineering microbial fuel cells and bioreactor systems.

Electroalcoholgenesis: Bioelectrochemical Reduction of CO_2 to Butanol

Medical University of South Carolina | Charleston, SC | $2,342,602

This project will develop a microbially catalyzed electrolysis cell that uses electricity (such as from solar photovoltaics) to convert carbon dioxide into liquid alcohol fuels. The process will produce butanol and will also be able to produce ethanol. The research team has a strong connection with Microbial Fuel Cell Technologies, LLC, in this area of research.

Electro-Autotrophic Synthesis of Higher Alcohols

University of California, Los Angeles | Los Angeles, CA | $4,000,000

The project team at the University of California, Los Angeles will develop microorganisms using synthetic biology and metabolic engineering techniques to use electricity instead of sunlight for biological carbon dioxide fixation and fuel synthesis. This process will repurpose carbon dioxide for use as a liquid fuel that can be readily used as a high octane gasoline substitute.

Electrofuels via Direct Electron Transfer from Electrodes to Microbes

University of Massachusetts, Amherst | Amherst, MA | $3,468,000

This project seeks to enhance the productivity of microbial electrosynthesis, a technology in which microorganisms directly use electric current (such as from solar photovoltaics) to convert water and carbon dioxide into fuels and other organic chemicals, potentially at much higher efficiencies than traditional photosynthesis and with less waste production, lower water usage, and no use of arable land. The short-term goal of the project is to optimize microorganisms already capable of microbial electrosynthesis for the production of butanol, which can be excreted from the cells to facilitate fuel processing.

Engineering a Bacterial Reverse Fuel Cell

Harvard Medical School - Wyss Institute | Boston, MA | $4,194,125

The goal of the proposed research from Harvard Medical School - Wyss Institute is to engineer a bacterium to absorb electrical current as an input and convert this energy into chemical energy in the form of a biofuel. The bacteria will be engineered to accept electrons in the form of current, to fix carbon dioxide, and to produce a biofuel, specifically octanol. Finally, a device that combines features of an electrochemical cell and a microbial fermenter will be developed.

Engineering E. coli as an Electrofuels Chassis for Isooctane Production

Ginkgo BioWorks, Inc. | Boston, MA | $6,668,000

Researchers at Ginkgo BioWorks seek to develop an “electrofuels chassis” by using engineered E. coli to convert carbon dioxide and electrical energy into short, branched-chain alkanes—molecules which cannot be produced using other known biosynthetic pathways. The target liquid fuel is isooctane, which fits well into the existing transportation fuel system in the U.S.

Engineering Ralstonia Eutropha for Production of Isobutanol (IBT), Motor Fuel from Carbon Dioxide, Hydrogen & Oxygen

Massachusetts Institute of Technology | Cambridge, MA | $1,771,404

Researchers at Massachusetts Institute of Technology are working on a project that relies on microbes that use hydrogen to convert carbon dioxide into liquid transportation fuels. Using Ralstonia eutropha, the team will redirect carbon flux to butanol production in a novel bioreactor system with increased performance.

Hydrogen-Dependent Conversion of Carbon Dioxide to Liquid Electrofuels by Extremely Thermophilic Archaea

North Carolina State University | Raleigh, NC | $2,749,976

This project seeks to combine the enzymes from a novel carbon fixation cycle in an extremophilic microbe that grows optimally near 75°C, with the hydrogen-utilizing hydrogenase enzyme from another extremophilic archaeon to construct a hybrid enzymatic pathway. The novel pathway will use hydrogen gas to convert carbon dioxide into C-2 and C-4 compounds that could serve as precursors to biofuels, such as butanol.

Novel Biological Conversion of Hydrogen and Carbon Dioxide Directly into Biodiesel

OPX Biotechnologies, Inc. | Boulder, CO | $5,997,490

Researchers at OPX Biotechnologies, will develop and optimize a unique, engineered microorganism that produces a biodiesel-equivalent fuel from renewable hydrogen and carbon dioxide, at costs of less than $2.50 per gallon. Water will be the primary byproduct. The project will draw on OPX's proprietary genomics technology and NREL's improved microorganisms for hydrogen utilization and carbon fixation for rapid metabolic engineering. The team will investigate the catalytic conversion of this microbial biodiesel into additional fuel molecules, most importantly jet fuel.

ARPA-E Program: Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)

The ability to store electricity and shift the power in time is becoming significantly more important as the U.S. increases its use of more eco-friendly renewable power. Renewable electricity generation is most commonly associated with wind and solar power, which when the sun stops shining or the wind stops blowing, is an intermittent and sometimes unreliable and undispatchable source of power. Storage allows energy producers, such as utility companies, to send excess electricity to storage devices. When wind and solar power ramps from available to unavailable or when electricity demand increases, energy can be taken from the storage devices and delivered to users that need it.

Today's electricity grid, the interconnected network that delivers electricity from suppliers to consumers, has virtually no storage. Those storage facilities that do exist use pumped hydropower, a system that pumps water uphill to a reservoir when excess electricity is available and then lets the water flow downhill through turbines to generate electricity when it is needed. While pumped hydropower storage works well on a cost effective basis in many cases, it can only be located in very limited areas of the country. The 12 projects that make up the GRIDS program seek to develop new energy storage technologies that are comparable in reliability and cost to pumped hydropower, and additionally, that are modular and can be deployed in any location in the country. These new technologies will enable the storage of electricity anywhere on the electricity grid across the U.S., allowing extra energy to be transmitted to geographies that need it the most at any given time. This ability to store and dispatch electricity on a reliable basis will be a key enabler of renewable electricity generation at high penetration while maintaining high reliability in electric supply.

GRIDS Project Highlights:

- Soluble Lead Flow Battery Technology
- Superconducting Magnet Energy Storage System with Direct Power Electronics Interface

GRIDS Project Highlight: Soluble Lead Flow Battery Technology

Lead Organization	General Atomics (San Diego, CA)
Award Amount	$1,986,308
Period of Funding	9/1/2010 to 2/28/2013
Primary Industry Area of Technology	Electricity Storage

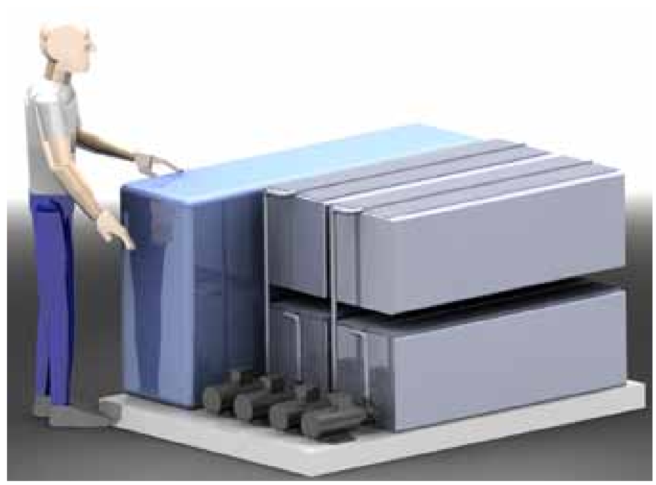
General Atomics in San Diego, California, along with the University of California San Diego, is working to develop a type of battery, known as a flow battery, able to store very large amounts of energy using chemicals that are stored in tanks outside the battery. Traditional lead-acid batteries, originally developed over a hundred years ago, work by using chemicals inside the battery to store electricity—as the chemicals are used up, the battery runs out of energy. General Atomics' battery will be similar to the lead-acid battery used in nearly every car on the road today, but with radical changes in the chemistry and flow that improve performance as needed for use on the grid.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

If successful, the soluble lead flow battery could provide energy at a lower cost and would need replacement only once every 20 years. The flow battery can be connected to the electricity grid to provide power or to smooth out power from intermittent renewables. With almost no stored electricity in today's electricity grid, electricity storage like this flow battery that can increase the energy storage of the electricity grid are increasingly important as cleaner, but intermittent, renewable power from solar and wind generation plants becomes more common.

PROJECT NEWS

After receiving ARPA-E funding, General Atomics' soluble lead flow battery technology was featured in a Forbes magazine article entitled Batteries That Go With The Flow (July 19, 2010). In the article, Leo Holland (who runs the battery program at General Atomics) claims that the technology would be cheaper than anything currently being proposed. Holland's goal is to build a very cheap, very durable battery that can last an hour—long enough to be useful to utilities.



With chemicals residing in external tanks, the design of General Atomics' flow battery allows for much more energy to be stored than in today's lead-acid batteries, at a much lower cost. Source: General Atomics

GRIDS Project Highlight: Superconducting Magnetic Energy Storage System with Direct Power Electronics Interface

Lead Organization	ABB (Raleigh, NC)
Award Amount	$4,200,020
Period of Funding	10/1/2010 to 9/30/2013
Primary Industry Area of Technology	Electricity Storage

Superconducting magnetic energy storage (SMES) is a solution for storage of electrical energy in a powerful magnetic field. ABB, based in Raleigh, North Carolina, is leading a team from Superpower, Brookhaven National Laboratory, and the University of Houston in developing an advanced superconducting magnetic energy storage system that will store significantly more energy than the current laboratory-level superconducting magnetic energy storage at a potentially lower cost than other extant storage technologies. The system will have the advantages of SMES, namely instantaneous dynamic response and nearly infinite cycle life, but with costs that approach or are less than those of lead-acid batteries as an electricity storage technology. To achieve these goals, ABB is working to propel the performance of each of the individual subsystems that compound the proposed superconducting magnetic energy storage far beyond the present state-of-the-art. The result will advance superconducting magnetic energy storage to a technology that is cost-competitive for delivering megawatt hours of stored electricity.

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

Superconducting magnetic energy storage systems have been in development for almost three decades; however, past SMES devices were designed to supply power only for short durations—generally less than a few minutes. This team aims to dramatically increase the amount of energy that can be stored in a superconducting magnetic energy storage device and to extend the duration during which power is available by building a SMES device with record high magnetic field. If successful, the superconducting magnetic energy storage device in this project will deliver large amounts of energy at very low cost for one hour, making it ideal for eventual use on the electricity grid as a competitor to batteries and other energy storage technologies.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

Today's electricity grid has little storage. Power must be generated as soon as it is needed, making renewable energy an often unreliable source due to the unpredictability of sources for wind and solar power. As the U.S. strives to make its power cleaner by connecting more renewable electricity sources to the electric grid, superconducting magnetic energy storage will enable a cheaper, cleaner, more reliable supply of electricity by adding energy storage to the grid.

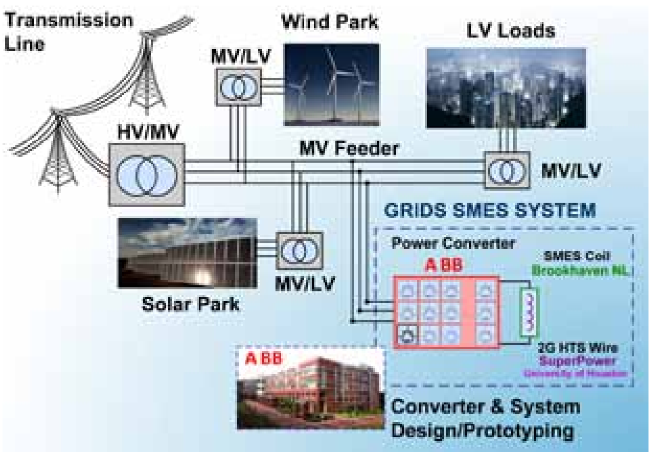


ABB is developing an advanced superconducting magnetic energy storage system (SMES) that will extend the duration of today's SMES from just a few minutes of power supply to an hour, at a cost competitive with lead-acid batteries. Source: ABB

All GRIDS Projects

A Robust and Inexpensive Iron-Air Rechargeable Battery for Grid-scale Energy Storage

University of Southern California | Los Angeles, CA | $1,459,324

Researchers at the University of Southern California and NASA's Jet Propulsion Laboratory are teaming together to develop a high-performance iron-air rechargeable battery for large-scale energy storage for the integration of renewable energy sources on the electricity grid. Iron-air batteries have the potential to store large amounts of energy inexpensively since they rely on inexpensive active materials: iron, which is abundant at extremely low cost, and oxygen, which is freely obtained from ambient air. However, current iron-air battery technologies have suffered from low round-trip energy efficiency and poor cycle life. To overcome these challenges in this project, novel strategies will be used to address these issues, including the use of additives at the iron electrode to suppress inefficient and parasitic losses, the application of nano-structured electrodes with thin films of catalysts layered at the air electrode that reduce losses, use of a unique cathode catalyst support that resists degradation and increases battery life, and a novel technique to avoid the absorption of carbon dioxide into the battery electrolyte. This project will develop an iron-air proof of concept rechargeable battery, the first step in the commercialization of this promising, low cost battery chemistry.

Development of a 100 kWh/100 kW Flywheel Energy Storage Module

Beacon Power Corporation | Tyngsboro, MA | $2,245,875

Beacon Power will lead a team in developing a next generation flywheel energy-storage module that stores four times the energy at one-eighth the cost-per-energy of the lowest cost state-of-the-art flywheels. The proposed system will use a "flying ring": a lightweight cylinder or tube of co-mingled fiber composite with bonded magnetic materials mounted on the structure. This configuration eliminates the central shaft and hub, allowing full utilization of the composite properties, thereby reducing cost and increasing energy density to 76 watt hours per kilogram. This design will be capable of very high cycling (greater than 40,000 full charge/discharge cycles) and will have a 20 year life, making it ideal to simultaneously address multiple grid-scale energy storage applications, including frequency regulation as well as emerging for ramping power to firm intermittent renewable generation.

Enhanced Metal-Air Energy Storage System with Advanced Grid-interoperable Power Electronics Enabling Scalability and Ultra-low Cost

Fluidic Energy, Inc. | Scottsdale, AZ | $2,993,128

Fluidic Energy, in cooperation with partner Satcon, proposes a high-risk-reward program to develop a novel, low cost, battery for intermittent renewable energy ramp support on the electric power grid. The proposed advanced multi-function energy storage prototype is highly scalable and will provide multiple modes of operation. The advanced multi-function energy storage device will be built around highly-efficient battery chemistry, but will use novel approaches to address traditional challenges for grid storage deployment, including limited rechargeability, low power density, and poor roundtrip efficiency. The advanced multi-function energy storage device will provide energy storage at low cost, in part by developing domestically-sourceable and geologically abundant active materials in an advanced battery chemistry. The system will be scalable to the megawatt-hour levels necessary for grid-scale energy storage.

Fuel-free, Ubiquitous, Compressed Air Energy Storage and Power Conditioning

General Compression, Inc. | Newton, MA | $750,000

General Compression will lead a team to develop a novel compressed air energy storage process (GCAES™) that is highly efficient and requires no fossil fuel. In this project, a team of industry and academic researchers will investigate near-isothermal CAES, which offers the potential of round-trip electrical efficiency up to 75 percent and a response time of less than one second. Unlike conventional CAES installations, no fuel will be burned in the expansion stage of the proposed process, dramatically reducing emissions and operating costs. If successful, this innovative compressed air energy storage technology could accelerate the integration of renewable electricity resources, particularly wind, into the grid.

Hydrogen-Bromine Flow Batteries for Grid-Scale Energy Storage

Lawrence Berkeley National Laboratory | Berkeley, CA | $1,642,508

Lawrence Berkeley National Laboratory and its team of industrial partners (DuPont, Bosch, 3M, and Proton Energy) will develop a hydrogen-bromine flow-battery system for grid applications. Hydrogen-bromine cells use two highly reversible and kinetically-favored electrodes to provide high round-trip efficiency. In addition, the proposed technology is expected to offer high power capabilities, thereby reducing the cost of stack components. The hydrogen-bromine system promises to meet the most stringent demands of costs, performance, lifetimes, and safety. To solve these technical challenges in this project, the Lawrence Berkeley National Laboratory team will apply novel technical approaches to deliver a proof-of-concept cell that will demonstrate the potential of this chemistry in grid-scale energy storage applications.

Low Cost, High Energy Density Flywheel Storage Grid Demonstration

Boeing | Huntington Beach, CA | $2,264,090

In this project, Boeing will use advanced fiber technology to develop a low cost, extremely high energy-density, high-efficiency flywheel technology for energy-storage. This project will increase flywheel energy density to allow for the practical use of this technology in longer-duration applications including renewable energy ramping on the electric power grid. To increase energy density, Boeing will develop a new proprietary fiber that will enable high rotor tip speeds. If successful in this high-risk technology development program, a flywheel system will be scalable to a utility-size unit (approximately 100 kilowatt hours) and amenable to factory production to achieve low cost ($100 per kilowatt hour).

Low Cost, High Performance 50 Year Electrodes

Primus Power Corporation | Alameda, CA | $2,000,000

Primus Power will develop an extremely durable, highly active, conductive, and inexpensive metal electrode for flow batteries. Flow batteries are ideal for bulk energy storage applications, but are often limited by the high cost and poor durability of the carbon materials used in the battery electrodes. In this project, Primus Power seeks to leverage processes informed by other chemical manufacturing industries to develop novel, low cost metallic flow battery electrodes. In addition, the team will develop a production process for the metal electrode by taking advantage of high volume processes used in the metals industry. Together, the low cost electrode and volume manufacturing process will result in a significant decrease in energy storage costs for the proposed flow battery technology, while simultaneously increasing the power density of the system. This project would yield a novel flow battery system that will provide scalable, low cost energy storage that is ideally-suited for addressing the renewable ramping challenge.

Soluble Lead Flow Battery Technology

General Atomics | San Diego, CA | $1,986,308

General Atomics and the University of California, San Diego, will develop an innovative flow battery technology based on lead-acid chemistry that significantly reduces costs and extends battery life. For a century, the lead-acid battery has been used in a variety of energy storage applications. While few battery technologies can match lead-acid's combination of low cost, high-efficiency, safety, and proven reliability, the lead-acid chemistry inherently suffers from poor cycle life when deeply discharged, as well as poor electrochemical materials utilization. The proposed flow battery will use novel electrode materials that greatly increase the surface area available for chemical reactions, minimizing the amount of excess lead in the battery. In addition, the electrodes will resist the corrosion that typically limits the cycle life of conventional lead-acid batteries. These innovations will result in a battery that easily can be scaled for grid-scale energy storage, but which costs less than existing technologies to accelerate the adoption and integration or renewable energy sources.

Superconducting Magnet Energy Storage System with Direct Power Electronics Interface

ABB, Inc. | Raleigh, NC | $4,200,020

ABB will lead a team from Superpower, Brookhaven National Laboratory, and the University of Houston in the development of an advanced superconducting magnetic energy storage system that will store significantly more energy than current superconducting magnetic energy storage at a fraction of the cost. In this project, the team aims to develop a 20 kilowatt ultra-high field superconducting magnetic energy storage system with a capacity of 3.4 MJ, a field of up to 30 T at 4.2 K, and roundtrip efficiency in excess of 85 percent. The system will have the advantages of superconducting magnetic energy storage, namely instantaneous dynamic response and nearly infinite cycle life, but with costs that will approach or potentially are less than those of lead-acid batteries. To achieve these goals, the performance of each of the individual subsystems that comprise the proposed system will be propelled far beyond the present state-of-the-art. The result will advance superconducting magnetic energy storage from a high-cost solution for delivering short bursts of energy to a technology that is cost competitive for delivering megawatt hours of stored electricity to address the renewable electricity ramping challenge.

Transformative Electromechanical Flow Storage System

United Technologies Research Center | East Hartford, CT | $2,999,963

United Technologies Research Center, in partnership with the University of Texas and Clipper Windpower, will develop a flow battery system that uses a novel cell design to deliver a ten times higher power density than current state-of-the art flow batteries. This breakthrough will enable a dramatic reduction in the size and cost of the cell-stack, which is the most expensive component of flow-battery systems. To take maximum advantage of this new cell-stack technology, a number of other innovative concepts will be incorporated into the system to transform the system to an energy-storage device with both rapid response times and long run times at rated power as needed for renewable energy support on the grid. A 20 kilowatt advanced prototype flow battery will be developed in this program that will lay the scientific and technical foundation for the development of a commercially-available grid-scale energy storage solution.

Transformative Renewable Energy Storage Devices Based on Neutral Water

Proton Energy Systems, Inc. | Wallingford, CT | $2,148,719

Proton Energy Systems and Penn State University will develop an advanced electrochemical energy storage device that incorporates a regenerative electrolyzer, fuel cell, and an alkaline membrane. Many fuel cells rely on acidic membranes which require costly noble metal catalysts and semi-precious metal components inside the cell stack to maintain conductivity. Transitioning to an alkaline membrane in the proposed regenerative electrolyzer and fuel cell will eliminate the highest-cost materials and enable higher efficiency through advanced system design. In this project, an inexpensive, alkaline membrane will be developed and then utilized in a 20 kilowatt reversible electrochemical advanced storage system that converts water to fuel and then back to water for grid-level electrical energy storage.

Zn MnO2 Flow Cell

CUNY Energy Institute | New York, NY | $2,997,133

In this project, the CUNY Energy Institute, in partnership with industry, will develop and construct a water-based flow-assisted battery for grid-scale energy storage. This novel battery starts with the same low cost materials found in disposable consumer-grade alkaline batteries, namely zinc and manganese dioxide, and then transforms the chemistry into a long-lasting, fully-rechargeable system. CUNY has initially demonstrated a zinc and nickel oxide battery that proves the basic science behind the concept of flow-assist for enabling zinc to repeatedly store electrical energy. In this project, the team will push this approach in a new direction by replacing nickel with reversible electrodes by leveraging key material innovations. The result of this effort will be a 25 kilowatt rechargeable system that lasts for 5,000 cycles, costs under $100 per kilowatt hour, and shows strong potential for scaling to megawatt-hour levels in grid-scale electric energy storage applications.

ARPA-E Program: Innovative Materials & Processes for Advanced Carbon Capture Technologies (IMPACCT)

Coal-fired power plants generate approximately 45 percent of electricity for the United States. While coal is a cheap and abundant natural resource, continued use of coal as an energy source will lead to increasing levels of greenhouse gases as carbon dioxide is released into the atmosphere. Capturing the emitted carbon dioxide and storing it would enable the continued use of domestic coal resources while reducing greenhouse gas emissions into the atmosphere. The primary challenge is the current cost of capturing carbon dioxide from a coal power plant, which is unacceptably high.

The IMPACCT program seeks to reduce the cost of carbon capture significantly through a combination of new materials, improvements to existing processes, and demonstration of new capture processes. Fifteen high-risk, high-reward projects are underway among a group of universities, businesses, and national laboratories. IMPACCT is pushing the boundaries of carbon capture research through technologies such as new liquid chemistries that dissolve carbon dioxide and a capture system inspired by jet engines that transforms carbon dioxide from a gas into pellets of dry ice. If successful, the IMPACCT program will secure the continued use of America's coal infrastructure without further increases in harmful greenhouse gas emissions.

IMPACCT Project Highlights:

- Low Cost Biological Catalyst to Enable Efficient Carbon Dioxide (CO_2) Capture
- Stimuli-responsive Metal-Organic Frameworks for Energy-Efficient Post-Combustion Carbon Dioxide Capture

IMPACCT Project Highlight: Low Cost Biological Catalyst to Enable Efficient Carbon Dioxide (CO_2) Capture

Lead Organization	Codexis, Inc. (Redwood City, CA)
Award Amount	$4,657,045
Period of Funding	7/1/2010 to 6/30/2012
Primary Industry Area of Technology	Carbon Capture

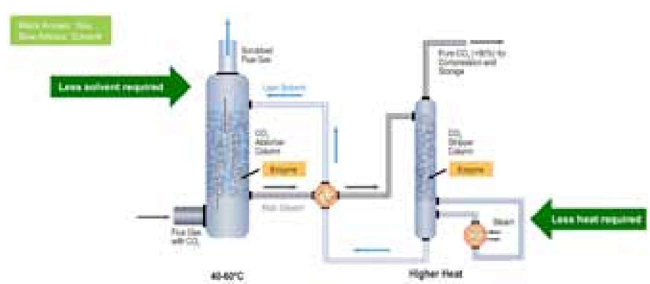
Codexis, Inc., a California-based company, is seeking to improve the process used to capture carbon dioxide, a greenhouse gas, produced as a result of burning coal in coal-fired power plants. Current carbon capture techniques for coal-fired power plants use chemical solvents—a substance cabable of reacting with carbon dioxide– that give rise to unacceptably high energy losses due to the excessive energy needed to regenerate these solvents. In an effort to develop a low cost catalyst for efficient carbon capture, Codexis is developing new forms of carbonic anhydrase to accelerate the absorption of carbon dioxide within the solvents. Despite the many attempts to engineer a robust carbonic anhydrase, no previous methods have succeeded in creating an enzyme that both withstands the harsh chemical environment found in coal-fired power plants and that is economically viable. Codexis is creating new forms of carbonic anhydrase enzyme that, if successful, would enable carbon dioxide capture under the challenging conditions in coal-fired power plants and transform the best available carbon dioxide capture processes into significantly more economical processes.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

By enabling more efficient carbon capture from coal-fired power plants, this project will improve the economic viability of such plants and allow us to reduce the environmental footprint of our existing coal infrastructure. Codexis projects that the cost of this type of carbon capture would create only a marginal increase in the cost of electricity, less than 35 percent, compared to the greater than 85 percent increase in the cost of electricity for capturing carbon using the best commercial processes currently available.

PROJECT NEWS

On December 2, 2010, Codexis announced a collaboration agreement of up to 16 months with a unit of Alstom SA, the world's third-largest power-equipment maker, and CO_2 Solution, Inc., to develop and test customized enzymes and related processes using specified solvents for use in power plants to reduce greenhouse gas emissions.

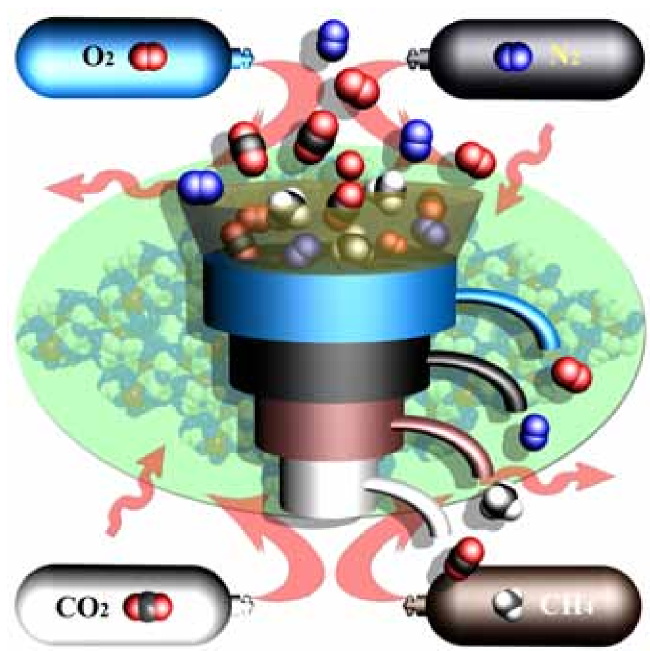


Codexis is using carbonic anhydrase as a catalyst for cost-effective carbon capture in the challenging conditions in coal-fired power plants. Source: Codexis, Inc.

IMPACCT Project Highlight: Stimuli-responsive Metal-Organic Frameworks for Energy-Efficient Post-Combustion Carbon Dioxide Capture

Lead Organization	Texas A&M Research Foundation (College Station, TX)
Award Amount	$1,019,874
Period of Funding	6/10/2010 to 6/30/2012
Primary Industry Area of Technology	Carbon Capture

A team from Texas A&M University is seeking to develop an innovative metal-organic framework, a relatively new class of materials that shows promise for capturing and removing carbon dioxide from coal-fired power plants. One of the primary factors leading to the high price of carbon capture with existing technologies is that the capture medium must be heated in order to release the carbon dioxide. In this project, researchers are developing precisely-controlled metal-organic frameworks that change their structure in response to relatively small changes in temperature. This resulting structural change allows the metal-organic framework to separate carbon dioxide from the rest of the flue gas more efficiently, which lowers the cost of carbon capture.



The innovative precision-controlled metal-organic framework that Texas A&M University is developing requires a relatively small change in temperature compared to existing carbon capture technologies, which will greatly reduce the cost of carbon capture.
Source: Texas A&M University

HOW THIS TECHNOLOGY IS TRANSFORMATIONAL

Chemicals currently used to dissolve and separate carbon dioxide are corrosive and require high temperature heating, which leads to an unacceptably high increase in the cost of electricity. The potential of this project is to use precision-controlled metal-organic frameworks to capture carbon dioxide with only a small change in temperature, which would greatly reduce the costs associated with carbon capture.

WHY THIS INNOVATION IS IMPORTANT FOR THE UNITED STATES

If successful, this technology would enable more cost-efficient carbon capture from coal-fired power plants. Coal is a major source of energy worldwide, so a technology that could enable the expanded use of coal without further increases in greenhouse gas emissions would be revolutionary. The U.S. could continue to use coal, a cheap and relatively plentiful resource in the U.S., and our existing coal plants, without adding to the billions of tons of carbon dioxide currently emitted.

All IMPACCT Projects

A High Efficiency Inertial CO_2 Extraction System–ICES
Alliant Techsystems, Inc. | Ronkonkoma, NY | $999,544

Researchers at ATK and ACENT will investigate the use of supersonic nozzles for rapid expansion and cooling of flue gas that will precipitate out the carbon dioxide for collection and capture. This technology, based on rocket nozzle and wind tunnel applications is a novel application to carbon capture and offers the potential for a simplified integration with existing power plants.

A Solvent/Membrane Hybrid Post-Combustion CO_2 Capture Process for Existing Coal-Fired Power Plants
University of Kentucky - Center for Applied Energy Research | Lexington, KY | $2,011,578

The University of Kentucky research team will develop a hybrid absorption solvent/catalytic membrane for post-combustion carbon dioxide capture process that can be retrofit onto existing coal-fired power plants. The membrane is a catalytic separator that couples nanofiltration separation and catalysis to produce a concentrated permeate. The membrane can be used with aqueous ammonium and some typical alkyl amines solutions. This catalytic membrane reactor could greatly reduce the energy penalty for carbon dioxide capture. Moreover, it could be conveniently integrated with traditional carbon capture processes.

Achieving a 10,000 GPU Permeance for Post-combustion Carbon Capture with Gelled Ionic Liquid-Based Membranes
University of Colorado at Boulder | Boulder, CO | $3,142,071

University of Colorado at Boulder will develop a novel gelled ionic liquid membrane, which provides mechanical rigidity into what is normally a liquid solvent, allowing extremely thin membranes to be fabricated. Since the membrane permeance increases as the membranes become thinner, higher fluxes of carbon dioxide can be selectively passed through the membrane, reducing the cost and size of membrane treatment for flue gas.

Catalytic Improvement of Solvent Capture Systems
Lawrence Livermore National Laboratory | Livermore, CA | $3,632,000

Synthetic small-molecule catalysts can greatly speed the absorption of carbon dioxide into liquid solvents and can enable solvents that bind CO_2 less tightly to achieve reduced energy consumption. This project combines scientific experience in creating synthetic small-molecule catalysts with industrial experience to make them operationally useful. The approach will also demonstrate the effective use of the catalysts under a range of process conditions.

Chemical and Biological Catalytic Enhancement of Weathering of Silicate Minerals as Novel Carbon Capture and Storage Technology
Columbia University | New York, NY | $1,266,675

In nature, carbon dioxide reacts with minerals such as magnesium silicates over a long period of time by an energetically favorable reaction. This type of reaction results in a stable precipitate. The focus of this work is on enhanced weathering by the acceleration of this natural reaction by using chelating agents that target brucite and silica layers. Enhanced weathering could provide an alternative to carbon sequestration that does not require monitoring, verification or accounting for stored carbon.

CO_2 Capture Process Using Phase-Changing Absorbents

General Electric Company | Niskayuna, NY | $3,017,511

This General Electric-led team will develop a novel, cost-efficient carbon dioxide capture process that uses a liquid absorbent that changes into a solid powder upon contact with carbon dioxide. The solid can then be isolated and the carbon dioxide can be released by heating. The absorbent then returns to its liquid form so that it can be reused. Because the absorbent solid contains a high percentage of carbon dioxide, the energy efficiency of the process is improved over current technology, and compression and capital costs are reduced. The goal is to achieve less than 10 percent parasitic power load at 90 percent carbon dioxide capture and at less than $25 per ton carbon dioxide capture cost. This approach also offers a smaller footprint than existing processes and could be retrofit onto existing plants.

CO_2 Capture with Ionic Liquids Involving Phase Change

Notre Dame University | Notre Dame, IN | $2,559,562

A recent discovery by researchers at Notre Dame University have identified a class of ionic liquid materials which undergo a phase transition from solid phase to liquid when reacting with carbon dioxide. A detailed synthetic study of these new compounds will aim to identify materials that are best suited for post-combustion capture applications. Lower heats of regeneration are required with these materials because the heat of fusion during the phase change from liquid to solid reduces the amount of energy needed to release the carbon dioxide that is captured.

Cryogenic Carbon Capture

Sustainable Energy Solutions | Provo, UT | $748,990

Cryogenic carbon capture is the process of removing carbon dioxide from flue gas by desublimation, followed by compression and transport of carbon dioxide in the condensed phase. With emerging process equipment and design concepts, cryogenic carbon capture has the potential to be more efficient and less expensive than current solvent-based carbon dioxide separation technologies. Sustainable Energy Solutions will develop and validate novel process components, and design a cryogenic carbon capture prototype system suitable for testing at coal-fired power plants. The approach is estimated to provide a 50 percent energy reduction for capturing carbon dioxide, in comparison to state-of-the-art amine-based solvent processes.

Electrochemically Mediated Separation for Carbon Capture and Mitigation

Massachusetts Institute of Technology | Cambridge, MA | $1,000,000

The MIT-led team will develop electrochemically mediated separation processes for post-combustion carbon dioxide capture at coal-fired power plants. Anticipated benefits include greatly increased energy efficiency for carbon dioxide capture, easier retrofitting of existing coal-fired power plants, and simpler integration with new facilities. The project will involve molecular modeling and experimental optimization of carrier structure, fabrication and evaluation of prototype separation units.

High Performance CO_2 Scrubbing Based on Hollow Fiber-supported Designer Ionic Liquid Sponges

Oak Ridge National Laboratory | Oak Ridge, TN | $887,609

The team from Oak Ridge National Laboratory and Georgia Tech will integrate new designer ionic liquids that capture carbon dioxide in flue gas with hollow fiber membranes that provide a robust, high surface area support. The objectives of this catch-and-release system are to cut the cost and energy associated with capturing carbon dioxide, as well as to design a platform that can be scaled up to coal-fired power plants across the country.

High Performance MOF/Polymer Composite Membranes for Carbon Dioxide Capture

Georgia Tech Research Corporation | Atlanta, GA | $1,000,000

Researchers at Georgia Tech will incorporate metal organic frameworks, new compounds that show great promise in carbon capture, into hollow fiber membranes for improved carbon dioxide selectivity. The use of hollow fiber membranes allows for high surface area, and the selective incorporation of metal organic frameworks into the polymer matrix will improve throughput and selectivity, helping to reduce capture costs.

High Throughput Discovery of Robust Metal-Organic Frameworks for CO_2 Capture

Lawrence Berkeley National Laboratory | Berkeley, CA | $3,867,851

The team led by Lawrence Berkeley National Laboratory will utilize robotic instrumentation tools and computational algorithms to accelerate the development of metal organic framework materials to capture carbon dioxide. There are many different metal organic framework structures that can be made, and the team will use nuclear magnetic resonance signals to quickly identify promising structures. This research is expected to lead to materials with improved selectivity and robustness that are worthy of large-scale testing and commercialization for carbon dioxide capture in power plants.

Low Cost Biological Catalyst to Enable Efficient CO_2 Capture

Codexis, Inc. | Redwood City, CA | $4,657,045

Codexis proposes to develop low cost enzymes for carbon capture from coal-fired power plants. Carbonic anhydrases, enzymes which catalyze carbon dioxide hydration, can enable the use of otherwise slow capture solvents with dramatically lower energy losses than current technology. Existing carbonic anhydrases are prohibitively expensive due to their low activity and short lifetime and high manufacturing (fermentation) costs. Codexis will apply its directed evolution technology to develop lower-cost thermophile-derived carbonic anhydrases with improved activity and stability and its strain evolution technology to develop a low cost manufacturing process for the enzyme.

Novel Non-aqueous CO_2 Solvent-Based Capture Process with Substantially Reduced Energy Penalties

RTI International | Research Triangle Park, NC | $2,200,000

RTI International and BASF are teaming up to explore a new class of non-aqueous solvents that exploit a new reversible carbon dioxide-solvent chemistry. The lower energy penalty results from the milder regeneration temperature that allows carbon dioxide to be released using less energy. The team estimates that this approach could reduce the regeneration energy so that it is 40 percent lower than that of conventional, state-of-the-art amine based solvent processes.

Stimuli-responsive Metal-Organic Frameworks for Energy-Efficient Post-Combustion Carbon Dioxide Capture

Texas A&M Research Foundation | College Station, TX | $1,019,874

Texas A&M will develop innovative metal organic framework based molecular sieves whose adsorption and desorption properties can be finely tuned by controlling their mesh size. This will enable more energy-efficient carbon dioxide capture and will reduce the cost of carbon dioxide capture by enhancing carbon dioxide/N2 selectivity at high carbon dioxide loadings and by greatly lowering the cost of regeneration. The team will demonstrate a process that it predicts can capture 90 percent of the carbon dioxide in flue gas with substantially reduced parasitic power demand.

Appendix A | ARPA-E Workshops

ARPA-E's program development process relies heavily on topical workshops that engage the leading experts in the technical community at-large and is a key component of ARPA-E's success. The workshops serve as a forum for ARPA-E to determine the state-of-the-art technology in a given field, to discuss solutions to the critical challenges identified, and determine aggressive, yet reachable, performance targets among the technical community. While not all workshops necessarily lead to ARPA-E programs, they do inform the direction of the program in particular energy technology areas. A listing of ARPA-E workshops is below. Summary reports from all ARPA-E workshops are available on the ARPA-E website: *http://arpa-e.energy.gov/EventsWorkshops/PastWorkshops.aspx*.

Power Electronics in Photovoltaic Systems (February 2011)

This joint ARPA-E/EERE workshop followed the August 2010 $1/W workshop and was aimed at identifying approaches to reduce the cost of installed photovoltaic (PV) systems to $1/W by 2017. The first day focused on "Solar ADEPT" (related to ARPA-E's Agile Delivery of Electrical Power Technology program) to address the challenges and opportunities associated with incorporating advanced power electronics into PV sources of electricity generation.

High Density Thermal Energy Storage (January 2011)

This workshop aimed to develop new ideas and identify the most promising R&D pathways for thermal energy storage. Thermal energy transport and conversion play a very significant role in more than 90 percent of energy technologies. Approximately two-thirds of thermal energy is wasted, and storage can significantly reduce this waste and enhance the efficiency of energy delivery and consumption.

Green Electricity Network Integration (December 2010)

This workshop addressed the challenges and opportunities associated with incorporating renewable energy sources into the Nation's power grid. The goal of the workshop was to develop new ideas and identify the most promising R&D pathways to better accommodate the alternatives to traditional electricity generation and the use of plug-in hybrid electric vehicles while improving the reliability, controllability, and performance of the power grid.

Critical Materials Technology (December 2010)

The goal of the workshop was to bring together thought-leaders from across scientific and engineering disciplines to identify potential transformational, early-stage applied research and development approaches to address technical challenges related to potential limited availability of critical materials in the energy sector such as rare earth materials. The importance of critical materials in the energy sector has been highlighted by the mismatch between the rapidly growing demands relative to limited global supply of rare earth materials.

Applied Biotechnology for Transportation Fuels (December 2010)

The workshop brought together thought leaders from distinct science and engineering communities to develop new ideas and identify practical approaches toward increasing the efficiency of light collection by biological systems and the conversion of that energy into liquid forms of chemical energy that can be used for transportation. Focus was directed towards the production of high-energy content fuel molecules by photosynthetic systems rather than processes that convert lignocellulose or other sources of biomass to usable fuels.

$1/W Workshop (August 2010)

This workshop was co-hosted by ARPA-E and the Office of Energy Efficiency and Renewable Energy's Solar Energy Technology Program. While DOE has a highly-productive photovoltaic program, a dramatic change is needed to develop products that can compete in large markets without significant subsidies. Experts specifically discussed how to achieve PV facilities priced at $1 per watt, fully-installed.

Power Technologies Workshop (February 2010)

This workshop aimed to gain a deeper understanding of those areas and technologies that have the highest potential to meet DOE's goal of developing the technical foundations necessary to improve the utilization of energy in power technologies. The workshop developed new directions in methods, components, and systems related to electrical energy conversion. ARPA-E later created the related Agile Delivery of Electrical Power Technology (ADEPT) program.

Energy from Wastewater Workshop (January 2010)

The goal of the workshop was to gain a deeper understanding of those areas and technologies that have the highest potential to meet DOE's goal of developing the technical foundations necessary to achieve net energy output and clean usable water from municipal and industrial wastewaters. ARPA-E sought to target high-risk R&D technologies which have been historically overlooked or are considered too risky for typical government-supported R&D funding.

Advanced Building Energy Technologies Workshop (December 2009)

The objectives of this workshop, co-hosted by ARPA-E and the DOE's Office of Energy Efficiency and Renewable Energy, were to gain a deeper understanding of those areas and technologies that have the highest potential to meet DOE's goal of developing the technical foundations necessary to enable massive reductions in energy consumption in buildings. ARPA-E later created the related Building Energy Efficiency Through Innovative Thermodevices (BEETIT) program.

Electrical Energy Storage for Vehicles Workshop (November 2009)

ARPA-E and the Department of Energy's Office of Vehicle Technologies held a workshop on the topic of energy storage for vehicles that served as an opportunity for ARPA-E leadership to engage with leading experts to obtain insight on vehicle energy storage technology areas that are ripe for and in strong need of transformational technology development. ARPA-E later created the related Batteries for Electrical Energy Storage in Transportation (BEEST) program.

Carbon Capture and Conversion Workshop (October 2009)

ARPA-E and the Department of Energy's National Energy Technology Laboratory held a workshop on the topic of carbon capture and conversion. The objectives of this workshop were to elicit a deeper understanding of the performance and cost factors that hinder the adoption of technologies for capture of carbon dioxide and conversion to useful commercial products, as well as to identify emerging opportunities/challenges for transformational "over the horizon" new technology approaches. ARPA-E later created the related Innovative Materials and Processes for Carbon Capture Technologies (IMPACCT) program.

Novel Approaches to Direct Solar Fuels Workshop (October 2009)

This workshop addressed the challenges and opportunities associated with Direct Solar Fuel Technologies. The goal of the workshop was to bring together thought-leaders from distinct science communities to collectively develop new ideas and identify the most promising R&D pathways to capture and utilize solar energy for the production of infrastructure-compatible, organic high energy transportable fuels. ARPA-E later created the related Electrofuels program as a direct outgrowth of this workshop.

Grid Scale Energy Storage Workshop (October 2009)

ARPA-E and the Department of Energy's Office of Electricity Delivery and Energy Reliability held a workshop on the topic of grid scale energy storage held in conjunction with the Electrical Energy Storage Applications and Technology Conference in 2009. This workshop served as an opportunity for ARPA-E leadership to engage with leading experts to obtain insight on grid scale energy storage technology areas ripe for, and in strong need of, transformational technology development. ARPA-E later created the related Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS) program.

Appendix B | Projects by Lead Organization's Location

State–City	ARPA-E Award Amount	Project	Lead Organization
AR–Fayetteville	$3,914,527	Low Cost, Highly-Integrated Silicon Carbide Multichip Power Modules for Plug-In Hybrid	Arkansas Power Electronics International, Inc.
AZ–Scottsdale	$2,993,128	Enhanced Metal-Air Energy Storage System with Advanced Grid-Interoperable Power Electronics Enabling Scalability and Ultra-Low Cost	Fluidic Energy, Inc.
AZ–Tempe	$5,205,706	Cyanobacteria Designed for Solar-Powered Highly Efficient Production of Biofuels	Arizona State University
AZ–Tempe	$5,133,150	Sustainable, High-Energy Density, Low Cost Electrochemical Energy Storage - Metal-Air Ionic Liquid Batteries	Arizona State University
AZ–Tucson	$5,000,000	Development of High Energy Li-S Cells for Electric Vehicles	Sion Power Corporation
CA–Alameda	$3,000,000	Airborne Wind Turbine	Makani Power, Inc.
CA–Alameda	$2,000,000	Low Cost, High Performance 50 Year Electrodes	Primus Power Corporation
CA–Berkeley	$4,996,311	Development Of Ultra-High Specific Energy Rechargeable Lithium/ Air Batteries Based On Protected Lithium Metal Electrodes	PolyPlus Battery Company
CA–Berkeley	$3,867,851	High Throughput Discovery of Robust Metal-Organic Frameworks for CO_2 Capture	Lawrence Berkeley National Laboratory
CA–Berkeley	$3,439,507	Development of an Integrated Microbial-ElectroCatalytic System for Liquid Biofuel Production from CO_2	Lawrence Berkeley National Laboratory
CA–Berkeley	$1,642,508	Hydrogen-Bromine Flow Batteries for Grid-Scale Energy Storage	Lawrence Berkeley National Laboratory
CA–Goleta	$2,950,000	High Performance GaN HEMT Modules for Agile Power Electronics	Transphorm, Inc.
CA–Hayward	$4,000,000	High Energy Density Lithium Batteries	Envia Systems
CA–Hayward	$1,153,975	Carbon Nanotube Membranes for Energy-Efficient Carbon Sequestration	Porifera, Inc.
CA–Huntington Beach	$2,264,090	Low Cost, High-Energy Density Flywheel Storage Grid Demonstration	Boeing
CA–Irvine	$399,800	Phononic Heat Pump	Material Methods, LLC
CA–Livermore	$3,632,000	Catalytic Improvement of Solvent Capture Systems	Lawrence Livermore National Laboratory
CA–Los Angeles	$4,000,000	Electro-Autotrophic Synthesis of Higher Alcohols	University of California, Los Angeles
CA–Los Angeles	$2,420,802	Thermal Energy Storage With Supercritical Fluids	University of California, Los Angeles

State–City	ARPA-E Award Amount	Project	Lead Organization
CA–Los Angeles	$1,459,324	A Robust and Inexpensive Iron-Air Rechargeable Battery for Grid-Scale Energy Storage	University of Southern California
CA–Los Angeles	$520,547	Compact MEMS Electrocaloric Cooling Module	University of California, Los Angeles
CA–Malibu	$5,058,752	Gallium-Nitride Switch Technology for Bi-Directional Battery-to-Grid Charger Applications	HRL Laboratories, LLC
CA–Menlo Park	$1,000,000	High Energy Density Capacitors	Recapping, Inc.
CA–Petaluma	$3,000,000	Adaptive Turbine Blades: Blown Wing Technology for Low Cost Wind Power	Caitin, Inc.
CA–Redwood City	$4,657,045	Low Cost Biological Catalyst to Enable Efficient CO_2 Capture	Codexis, Inc.
CA–Richmond	$1,750,072	Carbon Nanotube Membrane Elements for Energy Efficient and Low Cost Reverse Osmosis	NanOasis Technologies, Inc.
CA–Riverside	$763,745	Quaternary Phosphonium-Based Hydroxide Exchange Membranes	University of California, Riverside
CA–San Diego	$1,986,308	Soluble Lead Flow Battery Technology	General Atomics
CA–Santa Clara	$4,373,990	Enabling Novel Cathode Electrode Design with Integrated Separator and Manufacturing Toolset for High Energy Prismatic Li-Ion Battery Cells	Applied Materials, Inc.
CA–Stanford	$1,501,742	The All-Electron Battery: A Quantum Leap Forward in Energy Storage	Stanford University
CA–Stanford	$5,006,011	Large-Scale Energy Reductions through Sensors, Feedback, & Information Technology	Stanford University
CA–Thousand Oaks	$5,089,144	High Biomass, Low Input Dedicated Energy Crops to Enable a Full-Scale Bioenergy Industry	Ceres, Inc.
CA–Thousand Oaks	$3,439,494	Integrated Power Chip Converter for Solid State Lighting	Teledyne Scientific & Imaging, LLC
CA–Thousand Oaks	$1,000,272	Optofluidic Solar Concentrators	Teledyne Scientific & Imaging, LLC
CO–Boulder	$5,997,490	Novel Biological Conversion of Hydrogen and Carbon Dioxide Directly into Biodiesel	OPX Biotechnologies, Inc.
CO–Boulder	$3,142,071	Achieving a 10,000 GPU Permeance for Post-Combustion Carbon Capture with Gelled Ionic Liquid-based Membranes	University of Colorado at Boulder
CO–Littleton	$9,141,030	Low-Contact Drilling Technology to Enable Economical EGS Wells	Foro Energy, Inc.
CO–Littleton	$4,886,155	Low Cost Electrochromic Film on Plastic for Net-Zero Energy Building	ITN Energy Systems, Inc.
CT–East Hartford	$3,098,883	Nano-Engineered Porous Hollow Fiber Membrane-Based Air Conditioning System	United Technologies Research Center
CT–East Hartford	$2,999,963	Transformative Electromechanical Flow Storage System	United Technologies Research Center
CT–East Hartford	$2,855,795	Water-Based HVAC System	United Technologies Research Center
CT–East Hartford	$2,263,898	CO_2 Capture with Enzyme Synthetic Analogue	United Technologies Research Center
CT–Wallingford	$2,148,719	Transformative Renewable Energy Storage Devices Based on Neutral Water	Proton Energy Systems, Inc.
DE–Newark	$4,475,417	High Energy Permanent Magnets for Hybrid Vehicles and Alternative Energy	University of Delaware
DE–Wilmington	$8,884,698	MacroAlgae Butanol	E.I. du Pont de Nemours and Company

State–City	ARPA-E Award Amount	Project	Lead Organization
FL–Gainesville	$1,000,531	A New Generation Solar and Waste Heat Powered Absorption Chiller	University of Florida
FL–Odessa	$681,322	Novel Membrane-Based Dehumidification System that Will Directly Manipulate Water Molecules via a Nano-Structured Polymer Membrane	Dais Analytic Corporation
FL–Orlando	$4,092,727	Solid-State All Inorganic Rechargeable Lithium Batteries	Planar Energy Devices, Inc.
GA–Atlanta	$2,399,765	Modular Thermal Hub for Building, Cooling, Heating and Water Heating	Georgia Tech Research Corporation
GA–Atlanta	$1,016,017	Highly Laminated, High Saturation Flux Density Magnetic Cores for On-Chip Inductors in Power Converter Applications	Georgia Tech Research Corporation
GA–Atlanta	$1,000,000	High Performance Metal Organic Frameworks/Polymer Composite Membranes for Carbon Dioxide Capture	Georgia Tech Research Corporation
GA–Atlanta	$998,619	Dynamic Control of Grid Assets Using Direct AC Converter Cells	Georgia Tech Research Corporation
IA–Ames	$4,416,852	A Genetically Tractable Microalgal Platform for Advanced Biofuel Production	Iowa State University
IL–Champaign	$1,715,752	Harvesting Low Quality Heat Using Economically Printed Flexible Nanostructured Stacked Thermoelectric Junctions	University of Illinois
IL–Naperville	$2,250,486	Energy Efficient Capture of CO_2 from Coal Flue Gas	Nalco Company
IN–Kokomo	$6,733,386	Advanced Power Semiconductor and Packaging	Delphi Automotive Systems, LLC
IN–Notre Dame	$2,817,926	Compact, Efficient Air Conditioning with Ionic Liquid Based Refrigerants	University of Notre Dame
IN–Notre Dame	$2,559,562	CO_2 Capture with Ionic Liquids Involving Phase Change	University of Notre Dame
KY–Lexington	$2,011,578	A Solvent/Membrane Hybrid Post-Combustion CO_2 Capture Process for Existing Coal-Fired Power Plants	University of Kentucky - Center for Applied Energy Research
MA–Amherst	$3,468,000	Electrofuels via Direct Electron Transfer from Electrodes to Microbes	University of Massachusetts, Amherst
MA–Boston	$6,668,000	Engineering E. coli as an Electrofuels Chassis for Isooctane Production	Ginkgo BioWorks, Inc.
MA–Boston	$5,349,932	Low Cost, High Energy and Power Density, Nanotube-Enhanced Ultracapacitors	FastCAP Systems Corporation
MA–Boston	$4,194,125	Engineering a Bacterial Reverse Fuel Cell	Harvard Medical School - Wyss Institute
MA–Cambridge	$6,949,584	Electroville: High Amperage Energy Storage Device - Energy Storage for the Neighborhood	Massachusetts Institute of Technology
MA–Cambridge	$5,975,331	Semi-Solid Rechargeable Power Sources: Flexible, High Performance Storage at Ultra-Low Cost	24M Technologies, Inc. / Massachusetts Institute of Technology
MA–Cambridge	$4,414,003	Advanced Technologies for Integrated Power Electronics	Massachusetts Institute of Technology
MA–Cambridge	$4,085,346	Affordable Energy from Water and Sunlight	Sun Catalytix Corporation
MA–Cambridge	$3,863,563	Bioprocess and Microbe Engineering for Total Carbon Utilization in Biofuel Production	Massachusetts Institute of Technology
MA–Cambridge	$3,204,080	Low Cost Rechargeable Magnesium-Ion Batteries with High Energy Density	Pellion Technologies, Inc.
MA–Cambridge	$1,771,404	Engineering Ralstonia Eutropha for Production of Isobutanol, Motor Fuel from Carbon Dioxide, Hydrogen & Oxygen	Massachusetts Institute of Technology
MA–Cambridge	$1,000,000	Electrochemically Mediated Separation for Carbon Capture and Mitigation	Massachusetts Institute of Technology

State–City	ARPA-E Award Amount	Project	Lead Organization
MA–Lexington	$4,000,000	1366 Direct Wafer: Enabling Terawatt Photovoltaics	1366 Technologies, Inc.
MA–Medford	$4,565,800	Conditionally-Activated Enzymes Expressed in Cellulosic Energy Crops	Agrivida, Inc.
MA–Newton	$750,000	Fuel-Free, Ubiquitous, Compressed Air Energy Storage and Power Conditioning	General Compression, Inc.
MA–Tyngsboro	$2,245,875	Development of a 100 kWh/100 kW Flywheel Energy Storage Module	Beacon Power Corporation
MA–Wilbraham	$8,325,400	Breakthrough High Efficiency Shrouded Wind Turbine	FloDesign Wind Turbine Corp.
MD–College Park	$500,001	Thermoelastic Cooling	University of Maryland
MI–East Lansing	$2,540,631	Wave Disk Engine	Michigan State University
MI–Warren	$2,698,935	Lightweight Thermal Energy Recovery System	General Motors Company
MN–St. Paul	$2,200,000	Shewanella as an Ideal Platform for Producing Hydrocarbon Biofuels	University of Minnesota
MO–Joplin	$7,200,000	Planar Na-Beta Batteries for Renewable Integration and Grid Applications	EaglePicher Technologies, LLC
MO–Rolla	$1,200,000	High Performance Cathodes for Li-Air Battery	Missouri University of Science and Technology
NC–Durham	$5,200,003	15 kV SiC IGBT Power Modules for Grid-Scale Power Conversion	Cree, Inc.
NC–Raleigh	$4,200,020	Superconducting Magnet Energy Storage System with Direct Power Electronics Interface	ABB, Inc.
NC–Raleigh	$3,000,000	Advanced Semiconductor Materials for High Efficiency Thermoelectric Devices	Phononic Devices, Inc.
NC–Raleigh	$2,749,976	Hydrogen-Dependent Conversion of Carbon Dioxide to Liquid Electrofuels by Extremely Thermophilic Archaea	North Carolina State University
NC–Research Triangle Park	$3,111,693	Catalytic Biocrude Production in a Novel, Short-Contact Time Reactor	RTI International
NC–Research Triangle Park	$2,200,000	Novel Non-Aqueous CO_2 Solvent-Based Capture Process with Substantially Reduced Energy Penalties	RTI International
NJ–Livingston	$1,000,000	Upgrading Refinery Off-Gas to High-Octane Alkylate	Exelus, Inc.
NY–New York	$2,997,133	Zn MnO2 Flow Cell	CUNY Energy Institute
NY–New York	$1,568,278	Metacapacitors	CUNY Energy Institute
NY–New York	$1,266,675	Chemical and Biological Catalytic Enhancement of Weathering of Silicate Minerals as Novel Carbon Capture and Storage Technology	Columbia University
NY–New York	$543,394	Biofuels from CO_2 Using Ammonia-Oxidizing Bacteria in a Reverse Microbial Fuel Cell	Columbia University
NY–Niskayuna	$3,017,511	CO_2 Capture Process Using Phase-Changing Absorbents	General Electric Company
NY–Niskayuna	$2,249,980	Transformational Nanostructured Permanent Magnets	General Electric Company
NY–Niskayuna	$949,533	Nano-Structured Scalable Thick-Film Magnetics	General Electric Company
NY–Ronkonkoma	$999,544	A High Efficiency Inertial CO_2 Extraction System - ICES	Alliant Techsystems, Inc.
OH–Cleveland	$2,254,017	High Power Titanate Capacitor for Power Electronics	Case Western Reserve University
OH–Columbus	$5,000,000	Pilot-Scale Testing of Carbon Negative, Product Flexible Syngas Chemical Looping	Ohio State University
OH–Columbus	$3,977,349	Bioconversion of Carbon Dioxide to Biofuels by Facultatively Autotrophic Hydrogen Bacteria	Ohio State University
OH–Columbus	$400,000	The Absorption-Osmosis Cooling Cycle	Battelle Memorial Institute

State–City	ARPA-E Award Amount	Project	Lead Organization
OH–Hudson	$3,269,965	High Efficiency, On-line Membrane Air Dehumidifier Enabling Sensible Cooling for Warm and Humid Climates	Advance Materials Products, Inc.
OH–Marysville	$5,992,676	Scaling and Commercialization of Algae Harvesting Technologies	Algaeventure Systems, Inc.
OH–Miamisburg	$1,999,447	Silicon-Coated Nanofiber Paper as a Lithium-Ion Anode	Inorganic Specialists, Inc.
OH–Strongsville	$4,519,259	Ammonothermal Bulk GaN Crystal Growth for Energy Efficient Lighting	Momentive Performance Materials, Inc.
OR–Portland	$5,000,335	Zinc Flow Air Battery, the Next Generation Energy Storage for Transportation	ReVolt Technology, LLC
OR–Portland	$458,265	Innovative Building-Integrated Ventilation Enthalpy Recovery	Architectural Applications
PA–Bethlehem	$560,809	Electric Field Swing Adsorption for Carbon Capture Applications	Lehigh University
PA–State College	$2,908,239	One-Ton Thermoacoustic Air Conditioner	Pennsylvania State University
PA–University Park	$1,500,000	Development of Rhodobacter as a Versatile Platform for Fuels Production	Pennsylvania State University
SC–Charleston	$2,342,602	Electroalcoholgenesis: Bioelectrochemical Reduction of CO_2 to Butanol	Medical University of South Carolina
TN–Oak Ridge	$887,609	High Performance CO_2 Scrubbing Based on Hollow Fiber-Supported Designer Ionic Liquid Sponges	Oak Ridge National Laboratory
TX–Austin	$1,223,400	Non-Equilibrium Asymmetric Thermoelectric Devices	Sheetak, Inc.
TX–College Station	$1,019,874	Stimuli-Responsive Metal-Organic Frameworks for Energy-Efficient Post-combustion Carbon Dioxide Capture	Texas A&M Research Foundation
UT–Provo	$748,990	Cryogenic Carbon Capture	Sustainable Energy Solutions
VA–Blacksburg	$1,000,000	Power Supplies on a Chip	Virginia Polytechnic Institute and State University
VA–Blacksburg	$1,000,000	Isolated Converter with Integrated Passives and Low Material Stress	Virginia Polytechnic Institute and State University
VA–Dulles	$2,530,958	Monolithic Silicon Carbide Anode Switched Thyristor for Medium Voltage Power Conversion	GeneSic Semiconductor, Inc.
WA–Kennewick	$3,000,617	Stirling Air Conditioner for Compact Cooling	Infinia Corporation
WA–Richland	$2,513,827	High Efficiency Adsorption Chilling Using Novel Metal Organic Heat Carriers	Pacific Northwest National Laboratory
WI–Milwaukee	$2,889,676	An Efficient, Green Compact Cooling System Using Magnetic Refrigeration	Astronautics Corporation of America

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As of September 30, 2010

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