Spotlight

Solving Challenges in Energy Storage

August 2018

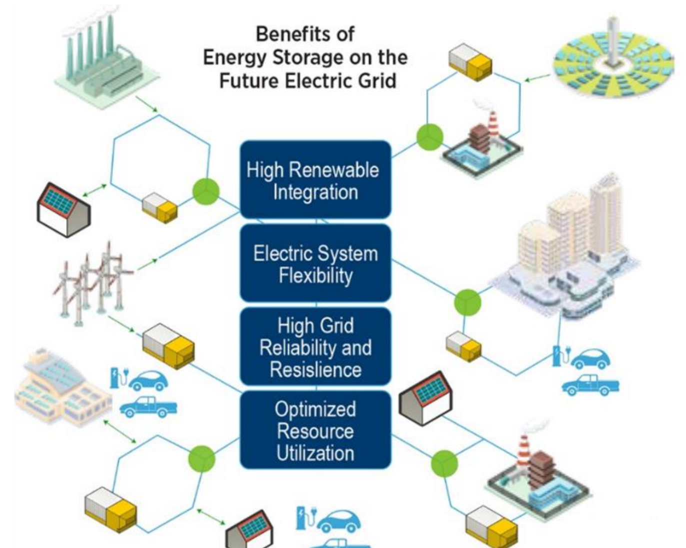
U.S. DEPARTMENT OF ENERGY | *Office of* TECHNOLOGY TRANSITIONS

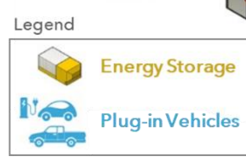
energy.gov/technologytransitions

Critical Need for Energy Storage

Advanced energy storage provides an integrated solution to some of America's most critical energy needs: electric grid modernization, reliability, and resilience; sustainable mobility; flexibility for a diverse and secure, all-of-the-above electricity generation portfolio; and enhanced economic competitiveness for remote communities and targeted micro-grid solutions.

Storage technologies strengthen and stabilize the U.S. grid by providing backup power, leveling loads, and offering a range of other energy management services. Electric vehicles (EVs) are also poised to become an integral part of this new grid paradigm as their batteries both draw power from and supply it back to the grid (when beneficial) – while eliminating tailpipe emissions.

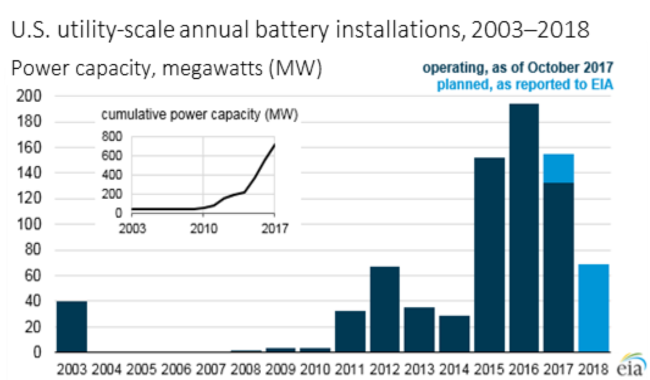




Energy storage systems, including plug-in vehicles, can enable a cleaner, more flexible, and reliable electric grid.

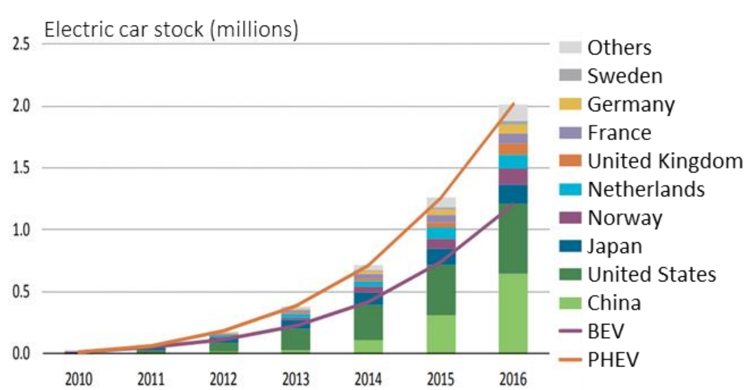
Recognizing that specific storage technologies best serve certain applications, the U.S. Department of Energy (DOE) pursues a diverse portfolio of energy storage research and development (R&D) to assure a continuous, affordable, and sustainable electricity supply. DOE forms R&D partnerships to leverage resources and accelerate progress throughout the entire technology development cycle. To address partner needs, DOE and its National Laboratories offer various arrangements and agreements for research. This approach has facilitated effective teamwork by the labs, industry, academia, other federal and state agencies and organizations—helping increase the commercial adoption of grid energy storage and EVs.

Growing Utility-Scale Energy Storage



Growing U.S. utility-scale battery installations, 2003–2018
Source: EIA. January 8, 2018.
eia.gov/todayinenergy/detail.php?id=34432

Rising Global EV Stocks

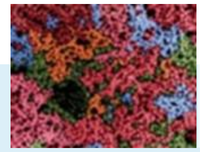


Rising global electric car stocks, 2010–2016,
Source: IEA. 2017.
iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

Challenges Facing Energy Storage Adoption

DOE investments in early-stage research have helped to significantly advance energy storage technologies that industry is unlikely to have developed on its own. Continued research activities with industry at specialized DOE facilities hold significant potential to further improve energy storage performance and cut costs. Continued R&D efforts target further progress to boost industry acceptance and enable the next generation of energy storage systems. Advances could accelerate growth in both utility-scale storage and EV ownership. As energy storage systems demonstrate their viability, policies and regulations may encourage broader deployment while ensuring systems maintain and enhance their resilience.[1]

DOE recognizes four key challenges to the widespread deployment of electric energy storage:[2]



Atomic structure of a solid electrolyte for safer batteries.

Start Small, Think Big

Today's energy storage devices are limited by the performance of their constituent materials. Overcoming these limitations requires understanding the myriad interactions that transfer ions or electrons in these devices and the physical and chemical processes that degrade them.

Powerful new computational, imaging, and characterization tools are illuminating the inner workings of energy storage at the atomic and molecular scales. Integration of this new knowledge will enable the scientific design of a new generation of energy storage devices that radically increase charge density and last longer by minimizing degradation from charge-discharge cycles.

Learn more about DOE Office of Science research priorities: science.energy.gov/~/media/bes/pdf/reports/2017/BRN_NGEES_rpt.pdf

Performance and Safety

Grid operators must be confident that energy storage systems will perform as intended within the larger network. Advanced modeling and simulation tools can facilitate acceptance—particularly if they are compatible with utility software.

Cost-Competitive Systems

Actual energy storage technology (e.g., the battery) contributes 30%-40% to total system cost; the remainder are attributed to auxiliary technologies, engineering, integration, and other services.

Regulatory Environment

Energy storage systems provide different functions to their owners and the grid at large, often leading to uncertainty as to the applicable regulations for a given project. Regulatory uncertainty poses an investment risk and dissuades adoption.

Industry Acceptance

Energy storage investments require broad cooperation among electric utilities, facility and technology owners, investors, project developers, and insurers. Each stakeholder offers a different perspective with distinct concerns.

---

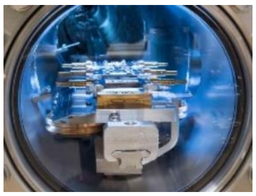
[1] "Energy Storage: Possibilities for Expanding Electric Grid Flexibility." National Renewable Energy Laboratory. February 2016. nrel.gov/docs/fy16osti/64764.pdf

[2] *Quadrennial Technology Review 2015*. U.S. Department of Energy. September 2015. energy.gov/quadrennial-technology-review-2015

Toward a More Robust U.S. Electric Grid

For grid applications, electricity must be reliably available 24 hours a day. Even second-to-second fluctuations can cause major disruptions that could potentially cost billions of dollars. New approaches to maximize energy storage capacity are essential to bring intermittent renewables into the grid and effectively manage electricity generation to meet peak demand.[3] DOE seeks to enable a smarter, more flexible electric grid by advancing research on novel materials and system components that resolve key challenges for energy storage systems.[4]

DOE's R&D Focus Areas for Energy Storage



Collaborative Center for ES Science, ANL

Concentrating solar tower at Crescent Dunes, LPO

Post-Test Facility, ANL

Materials. Improved energy storage system costs, service life, durability, and power density are made possible by innovative materials that enable new battery chemistries and component technologies, such as low-cost membranes for flow batteries, sodium-based batteries, high voltage capacitors, wide bandgap materials, and devices for power electronics.

Power Technologies. Storage systems can be designed with a broad portfolio of technologies, each with its own performance characteristics that makes it optimally suitable for certain grid services. Established large-scale technologies, such as pumped hydro and compressed air energy storage, are capable of long discharge times (tens of hours) and high capacity. In contrast, various electrochemical batteries and flywheels are positioned around lower power applications or those suitable for shorter discharge times (a few seconds to several hours).

Power Electronics. Power electronics, such as switches, inverters, and controllers, allow electric power to be precisely and rapidly controlled. Energy storage and power electronics improve a power supply reliability and responsiveness.

Grid Analytics and Policy. Analytical and multi-physics models to understand risk and safety of complex systems, optimization, and efficient utilization of energy storage systems in the field. Validated data sets support development of codes and standards to optimize use of storage resources across the U.S. electricity infrastructure.

Safety and Reliability Testing. Advanced simulation and modeling and real-world demonstration projects increases the understanding of safety and reliability of energy storage systems.

Key Grid Energy Storage Technologies

Batteries. Electrochemical battery types include lithium-ion, sodium sulfur, lead acid, and flow batteries. These batteries vary in energy density, power performance, lifetime charging capabilities, safety, and cost.

Pumped Hydroelectric Storage. Water pumped from a low reservoir to a high one is later released through a hydroelectric turbine to generate electricity as needed.

Compressed Air Energy Storage. Compressed air is stored in an underground cavern until it is heated and expanded in a turbine to generate electricity.

Thermal Storage. Heat is captured and stored in water, molten salts, or other working fluids for later use in generating electricity, particularly when intermittent resources (e.g., solar) are unavailable.

Hydrogen. Hydrogen can be stored and used later in fuel cells, engines, or gas turbines to generate electricity without harmful emissions.

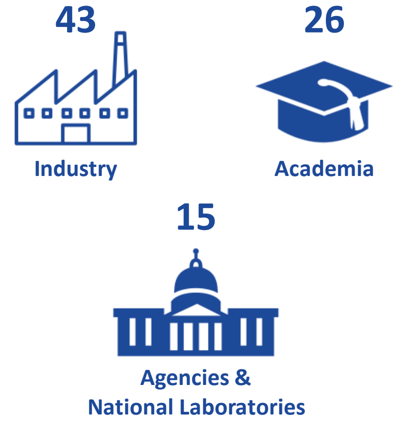
Flywheels. Electric energy is stored as kinetic energy by spinning a rotor in a frictionless enclosure. Flywheels are useful for applications such as power management.

---

[3] DOE, Basic Energy Sciences, "Science for Improving U.S. Energy Flow." science.energy.gov/~/media/bes/images/placemats/Back_3103x2024.jpg

[4] DOE, Office of Electricity, "Energy Storage." energy.gov/oe/activities/technology-development/energy-storage

DOE Office of Electricity Partners as of 2018



Advanced Energy Storage Projects Boost U.S. Technology Leadership

DOE and its National Laboratories have worked with industry, academia, other federal and state agencies and organizations for decades to develop and optimally integrate innovative storage technologies, power electronics, and controls into complete energy storage systems. Advanced energy storage benefits the power industry, its customers, and the nation:

- **Affordability.** Meet system needs at minimal costs
- **Efficiency.** Optimize assets and reduce delivery losses
- **Flexibility.** Handle dynamic supply and demand and accommodate diverse technologies
- **Reliability.** Consistently deliver high-quality power
- **Resiliency.** Maintain critical functions/quick recovery

DOE RDD&D projects are helping U.S. businesses deliver these benefits while solidifying America's leadership in global energy storage technology.

1976-1991

DOE labs research alternative energy and utility energy storage technologies, including rechargeable batteries.

1991-2011

Scope expands to RDD&D of integrated energy storage systems, power electronics, and controls—winning R&D 100 awards

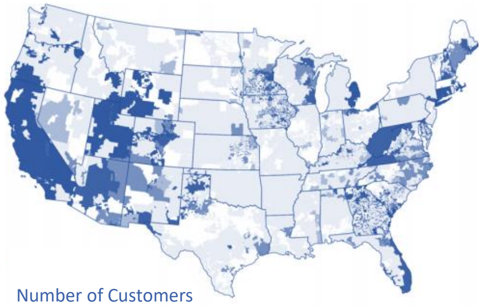
2011-2015

16 stationary storage projects demonstrate technology readiness to deliver backup power and auxiliary utility services; onboard technologies improve range, price, and efficiency

2015-2018

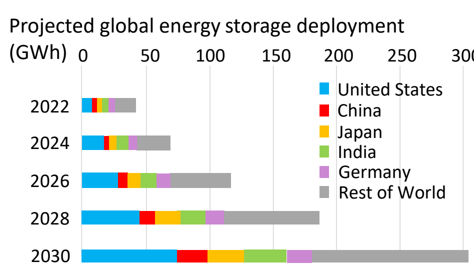
DOE licenses technologies to industry; provides data and modeling to support commercialization; explores novel storage approaches (e.g., flywheels, compressed air); and helps pave the way for interconnections and further market growth.

Markets for Behind-the-Meter Battery Energy Storage



Number of commercial electricity customers who can subscribe to tariffs with demand charges in excess of $15/kW. [nrel.gov/docs/fy17osti/68963.pdf]

Projected Global Deployment of Energy Storage



[Adapted from Bloomberg New Energy Finance 2017]

Improving Onboard Vehicle Energy Storage

Improved batteries and hydrogen fuel cells (HFCs) for electric-drive vehicles will assure their economic, environmental, and market sustainability. Transitioning to a vehicle fleet powered by these devices could eliminate tailpipe emissions and cut emissions overall, depending on the technology mix. While a variety of EVs and HFCs are now available, research developments could further enhance their consumer appeal. RDD&D focuses on reducing the cost, volume, weight, and charging time of batteries and fuel cells, while simultaneously improving performance (power, energy, durability, and tolerance in harsh conditions).[5]

Strategic DOE R&D Areas for On-Vehicle Energy Storage

Battery chemistry research, NREL

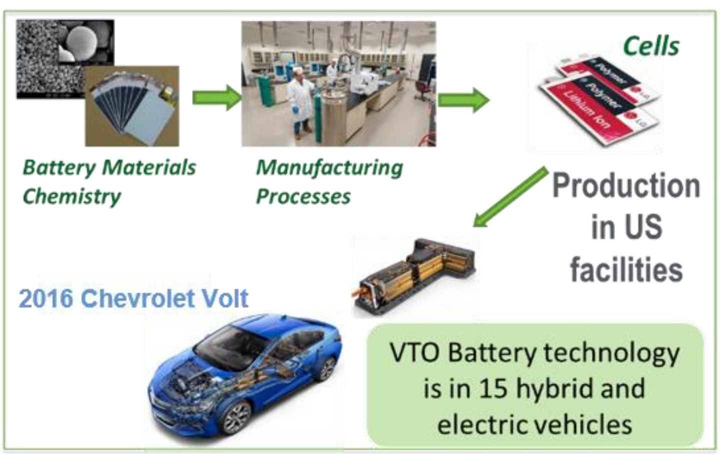
INL's Battery Test Center

Advanced Cell Materials. Researchers apply scientific tools and models in exploring electrochemical interactions and developing novel materials to improve energy storage capacity and efficiency while lowering costs.

System Integration, Analysis, and Testing. New battery and cell systems that integrate novel materials and technologies are carefully analyzed and tested to assess their performance and potential to reduce cost, weight, and size while improving performance and safety. This research aims to ensure these systems meet specific goals for particular vehicle applications.

Electrification R&D. Research on Extreme Fast Charging tackles the challenges in developing a convenient and affordable grid and charging infrastructure that will enable low-effort energy replenishment in 15 minutes or less.

EV Batteries Extend Range at Lower Cost



DOE is developing new chemistry and cell technologies to push EV battery costs below $100/kWh, increase range to over 300 miles, and charge in under 15 minutes.[5]

Second Use for EV Batteries on the Grid

EV batteries are typically retired from vehicle use when they no longer meet the high standard performance thresholds for that application. These batteries still offer significant storage capacity and can be economically reconditioned and redeployed to store energy for the stationary grid—such as peak-shaving services. The National Renewable Energy Laboratory is exploring this reuse to help increase EV ownership and reduce the cost of grid-connected energy storage systems.

"Energy Storage: Possibilities for Expanding Electric Grid Flexibility." National Renewable Energy Laboratory. February 2016.

---

[5] DOE, Vehicle Technologies Office. "Batteries, Charging, and Electric Vehicles." energy.gov/eere/vehicles/batteries-charging-and-electric-vehicles

Researchers at Argonne National Laboratory (ANL) and other National Labs explore strategies to shorten EV charging time. (Image: ANL)

Advanced Battery Research Boosts U.S. Electric Vehicle Sales

Major advances in battery technologies are driving U.S. sales of electric vehicles. Through December 2017, 757,445 plug-in electric vehicles have been sold in the United States. DOE has been a leader in battery R&D investment, investing $1.6 billion dollars in battery R&D between 1992 and 2017. Nearly all battery technology on the road today can be traced to DOE research.

Research: Since 1976, DOE funded scientists have built a broad foundation for advances in energy storage technologies ranging from nickel-metal hydride batteries to lithium-ion battery technologies and beyond lithium-ion chemistries. In 2017, VTO developed and verified innovative lithium-ion technology with the potential to reduce battery pack cost to $219/kWh of useable energy, an approximately 80% reduction since 2008.

Disclosure and IP Protection: This research yielded valuable technologies, resulting in 222 patents for batteries, ultracapacitors, and supporting components by 2009.

Jobs: Nearly 80% of the 260,000 alternative fuel vehicle jobs in the USA focus on hybrids and plug-in electric vehicles.

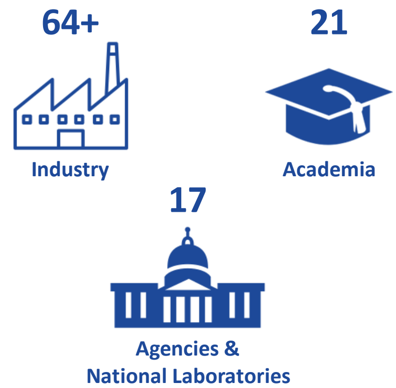
Learn more at: energy.gov/revolution-now

Research Example: Together with the United States Advanced Battery Consortium (USABC), DOE research enabled the core battery cell technology used in vehicles such as the Chevy Bolt and Ford Focus EV.

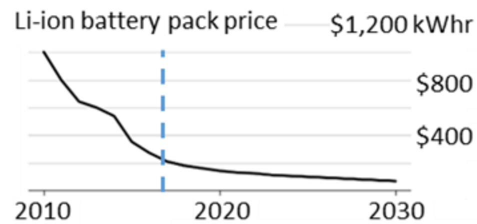
The cell, which contains a graphitic anode and a mixture of layered nickel-manganese-cobalt and manganese spinel oxides, was developed in collaboration with LG Chem Michigan from early 2004 through 2012.

It also contains promising cathode technology that can improve energy density by 30-40% over conventional cathode materials. The innovative, "lithium-rich" nickel-manganese-cobalt oxide cathode material, originally developed at Argonne National Laboratory, has been licensed to GM, LG Chem, BASF, Toda America, and Envia. Members of this cathode material "family" can operate at higher voltages and achieve much higher capacities than conventional cathode materials, leading to batteries with higher energy density.

DOE Vehicle Technologies Office Partners as of 2018

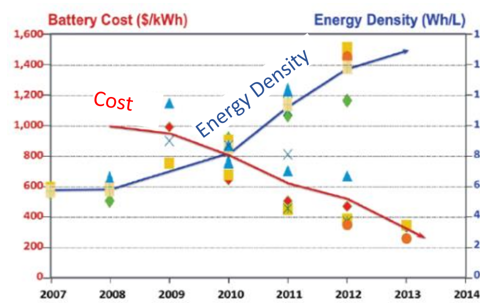


Novel Materials Lower Battery Costs



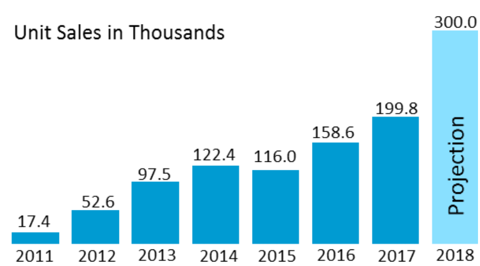
[Adapted from Bloomberg New Energy Finance 2018]

EV Batteries Increase Energy Density to Extend Range at Lower Cost



"EV Everywhere Grand Challenge." DOE Energy Efficiency and Renewable Energy Office. January 2014. energy.gov/sites/prod/files/2014/02/f8/eveverywhere_road_to_success.pdf

Rising Annual EV Sales



[Data from Inside EV Sales Scorecard]

Partners Advance Energy Storage with DOE

U.S. DEPARTMENT OF ENERGY
Office of ELECTRICITY
Office of ENERGY EFFICIENCY AND RENEWABLE ENERGY
Office of SCIENCE
Office of TECHNOLOGY TRANSITIONS
arpa·e CHANGING WHAT'S POSSIBLE
U.S. DEPARTMENT OF ENERGY LOAN PROGRAMS OFFICE

DOE invests in energy storage R&D to stimulate significant technology progress—boosting U.S. competitiveness in global markets. Through an array of Program Offices that oversee energy storage R&D, DOE has stimulated significant progress in energy storage over the past several decades.

DOE supports de-risking energy storage technology through R&D partnerships among its National Laboratories with industry, academia, federal and state agencies, and a range of public-private consortia.[6] These multi-institutional partnerships support the advancement of energy storage technologies for applications in vehicles and the electric power sector and the commercialization of new energy technologies. The consortia involving industry leave participants free to build on shared information to create proprietary outcomes of commercial value. Each consortium is focused on a vision or goal to attain specific technology performance and cost thresholds for industry uptake and commercialization, while basic research partnerships sustain leading-edge science and discovery.

USABC — United States Advanced Battery Consortium LLC	Develop electrochemical energy storage technologies that support commercialization of fuel cell, hybrid, and electric vehicles.
PowerAmerica	Transition existing silicon-based systems to wide bandgap technology for enhanced power and efficiency.
Battery500 Consortium	Build a battery pack with a specific energy of 500 watt-hours per kg, compared to the 170-200 watt-hours per kg in today's typical EV battery.
GRID Modernization Initiative, U.S. Department of Energy	Established a strategic partnership between DOE and the National Laboratories to modernize the nation's electric grid.
JCESR — Joint Center for Energy Storage Research	Deliver transformational understanding, new concepts, and innovative materials for high performance, next generation batteries for the grid and transportation.
Energy Frontier Research Centers	Several of the Office of Science Energy Frontier Research Centers address use-inspired basic research for electrochemical energy storage.

Advancing the State of the Art through Strategic Investments in Innovative Energy Storage Technologies

In May 2018, Advanced Research Projects Agency-Energy (ARPA-E) announced up to $30 million in funding for projects as part of a new program: Duration Addition to electricitY Storage (DAYS). DAYS project teams will build innovative storage systems that can provide power to the electric grid for durations of 10 to 100 hours—opening new prospects to increase grid resilience and integrate intermittent renewable resources.

Learn more at: arpa-e.energy.gov/?q=news-item/department-energy-announces-funding-support-long-duration-energy-storage

The DOE Loan Programs Office has helped launch and finance many innovative energy storage projects in the United States. Key examples: (1) concentrating solar power plants with thermal energy storage, (2) Nissan North America's construction of one of the largest advanced battery manufacturing plants in the country, and (3) Tesla Motors' production of specially designed, all-electric plug-in vehicles and battery packs in Fremont, California.

Learn more at: energy.gov/lpo/tesla

[6] "Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing—Supplemental Information." Quadrennial Technology Review 2015. DOE. 2017. energy.gov/sites/prod/files/2017/02/f34/Ch6-SI-Public-Private-Consortia-and-Technology-Transition-Case-Studies.pdf

DOE Leverages Unique Energy Storage Capabilities

DOE's scientific and technical capabilities are rooted in its system of National Laboratories—world-class institutions that constitute the most comprehensive research and development network of its kind.

The DOE National Laboratories possess a unique collection of scientific expertise and highly specialized facilities. Collectively, these assets play a vital role in helping the United States maintain the science and technology leadership needed to sustain economic superiority in a dynamic and innovative global economy.

Researchers at the National Laboratories and other DOE-funded facilities actively collaborate with partners in industry, academia, and government to develop transformational technologies, including those essential to energy storage.

Partnership Agreements with DOE National Laboratories

Industry, academia and other entities can access the specialized expertise and facilities of the DOE National Laboratories by entering into collaborative research agreements. A variety of partnership mechanisms are available to suit the diverse needs of the broad U.S. research community. Types of partnership agreements include:

- Agreements for Commercializing Technology (ACT)
- Cooperative Research & Development Agreements (CRADA)
- Material Transfer Agreements
- Strategic Partnership Projects (SPP)
- Technical Support Agreements
- Technology Licensing Agreements
- User Agreements

In fiscal year 2016, partners using the ACT, CRADA, or SPP mechanisms for energy storage research included 63 unique non-federal partner organizations working on 80 active agreements. These partners contributed $4.5 million to this work covered by agreements included 30 CRADAs, to which DOE contributed $2.1 million. In addition, three other federal agencies engaged the labs on 16 active agreements and contributed $2.9 million to this work.

For more information on how to work with the National Laboratories, please refer to the 2016 *Guide to Partnering with DOE's National Laboratories*, inl.gov/wp-content/uploads/2016/05/Revised-Guide-Partnering-with-National-Labs-Final.pdf

Core Capabilities in Energy Storage

Our National Laboratory System uses its world-class expertise and facilities to lead basic discovery research, technology development, and demonstrations. The following laboratories hold core capabilities in energy storage R&D:

Ames Laboratory
Argonne National Laboratory
Brookhaven National Laboratory
Idaho National Laboratory
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
National Renewable Energy Laboratory
Oak Ridge National Laboratory
Pacific Northwest National Laboratory
Sandia National Laboratories
Savannah River National Laboratory
SLAC National Accelerator Laboratory

Learn more at energy.gov/downloads/annual-report-state-doe-national-laboratories

DOE's System of National Laboratories has tens of thousands of square feet of laboratory space dedicated to accelerating the development of the next generation of energy storage technologies.

The Labs are home to multiple facilities and collaborative research groups that solve energy storage problems through multidisciplinary research.

IP Bundling of Energy Storage Technologies Available for Licensing

To expedite technology partnerships in energy storage, DOE piloted an IP Bundling Project. Under this project, six DOE National Laboratories develop technology bundles that identify complementary intellectual property (IP), scientific expertise, and technological capabilities across multiple laboratories and offer them to industry partners under one partnership agreement.

Laboratory Partnering Service (LPS)

LPS is an online platform that enables public access to world-leading DOE National Laboratory energy experts, project marketing summaries, and licensing opportunities.

For additional and up-to-date all DOE available technologies and more information visit: labpartnering.org/

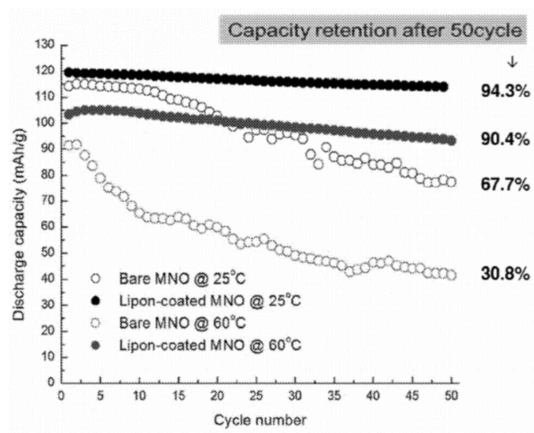
Argonne NATIONAL LABORATORY | BERKELEY LAB | BROOKHAVEN NATIONAL LABORATORY | NREL NATIONAL RENEWABLE ENERGY LABORATORY | OAK RIDGE National Laboratory | SLAC NATIONAL ACCELERATOR LABORATORY

Three Energy Storage IP Bundles are available for commercialization:

1. High-Energy, High-Voltage, Lithium-Ion Batteries

Materials research continues to be critical to widespread adoption of Li-ion batteries. In particular, efforts seek to increase cathode voltage while minimizing capacity losses at the lowest possible system cost. Current cathodes perform at approximately 150–180 mAh/g at 3.5–3.8 V (Li), giving <700 Wh/kg oxide energy. The USABC goal for the price vs. cost of Li-ion batteries is $125/kWh.

This IP bundle emphasizes novel materials that will yield high-voltage, high-energy batteries. The included technologies stem from research at Argonne, Lawrence Berkeley, and Oak Ridge National Laboratories funded by the EERE Vehicle Technologies Office.



Patent No. US 9837665

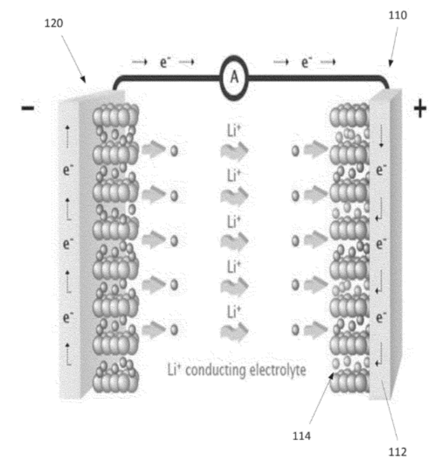
Intellectual Property Included in this Bundle

- Electroactive materials for rechargeable batteries. US 9478794B2
- Lithium ion battery incorporating heat-treated carbon black that limits the reactivity of the carbon black and electrolyte. US 9368798
- Cathode material having an alkaline source for improved specific capacity, energy density, cycle life, and stability for rechargeable batteries including, but not limited to Li-S. US 9012091
- Lithium phosphorus oxynitride protective layer of coating between the cathode and electrolyte to allow Li-ion operation at high temperature and high voltage. US 9837665B2
- Electrolyte solvent enabling high-temperature operation of Li-ion battery. US 9005822
- Non-aqueous electrolyte solution preventing solid electrolyte interface films on carbonaceous electrodes for improved performance. US 9246187
- High-voltage lithium-ion battery with fluorinated electrolytes and lithium additive for improved performance at high temperature and voltage. US 2015-0050561
- Electrolyte composed of lithium hexafluorophosphate for high-voltage applications providing longer life stability and better cycling performance. US 2016-0099484

2. Lithium-Sulfur Batteries

Poor conductivity and rate capability based on sulfur are intrinsic characteristics of the Li-S battery system that limit performance. Current challenges include Li-polysulfide formation due to dissolution of sulfur in the electrolyte and the formation of dendrites in the lithium-metal anode.

This IP bundle combines advanced materials in all components of the battery to mitigate these challenges. Sulfur is a low-cost raw material, and Li-S batteries could obtain specific energy densities of nearly five times that of Li-ion technology. The included technologies stem from research at Argonne and Lawrence Berkeley National Laboratories, funded by the EERE Vehicle Technologies Office.



Patent No. US 2016-0308209

Intellectual Property Included in this Bundle

Porous graphene nanocages for battery applications. US 9590248

Ultra-stable cathodes for Lithium-Sulfur batteries. US 2016-0308209

Sulfur cathode hosted in porous organic polymeric matrices. US 2014-0255794

Lithium-Sulfur batteries. US 2017-0033406

Lithium-Sulfur electrolytes and batteries. US 2014-0023936

Non-aqueous electrolytes for electrochemical cells. US 9368832

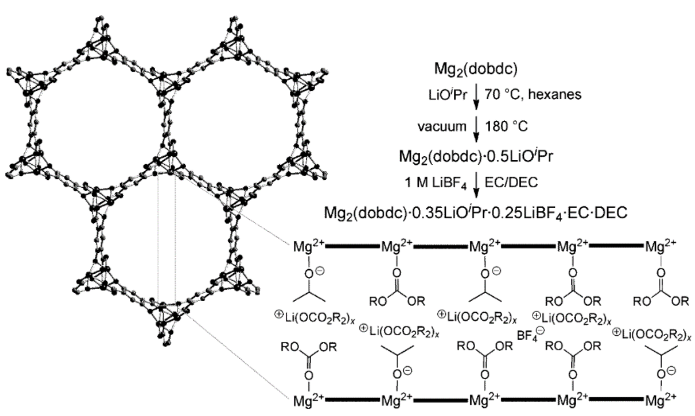
Core-shell structured nanoparticles for Lithium-Sulfur cells. US 2015-0311508

Durable carbon-coated Li2s core-shell materials for high-performance lithium/sulfur cells. US 2016-0248084

3. New Materials for Solid State Li-Ion Batteries

This bundle provides Li-ion producers strategic pathways to increase battery power, energy density, lifetime, and safety with novel alternatives that exhibit excellent electrochemical performance.

The available technologies, developed at Argonne and Lawrence Berkeley National Laboratory, include clean anodic Li films for longer life in rechargeable Li-ion batteries, solid Li electrolytes for increased safety, and block copolymer-based cathodes that can transport electronic charge and ions. Technologies developed with support from the EERE Technologies Office.



Patent No. US 9525190B2

Intellectual Property Included in this Bundle

Clean anodic Lithium films for longer life, rechargeable Lithium-Ion batteries. US 2017-0110714A1

Modified metal organic framework (MOF) as a solid Lithium electrolyte for safer Lithium-ion batteries. US 15083029, US 9525190B2

Block copolymer cathode binder to simultaneously transport electronic charge and ions. US 8552144

Materials for solid-state electrolytes and protective electrode coatings for Lithium batteries. US 2015-0364747A1

Individual Energy Storage Patents Available for Licensing

Anodes

Lithium air battery having a cross-linked polysiloxane separator
US 9478782, Argonne National Laboratory

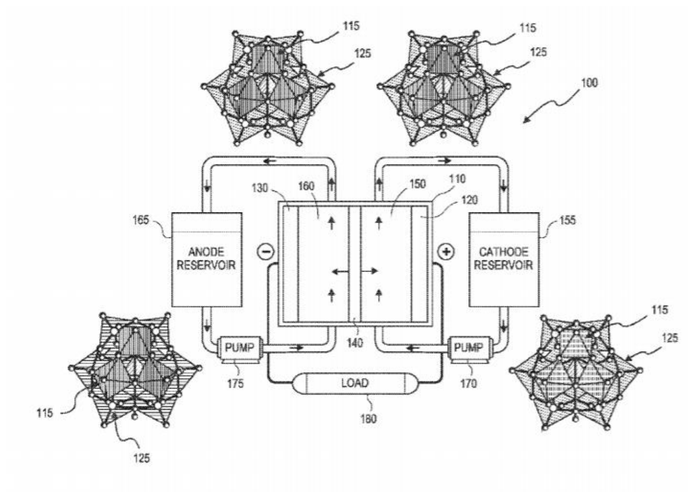
Modified carbon black materials for lithium-ion batteries
US 9368798, Lawrence Berkeley National Laboratory

Multi-layer coatings for bipolar rechargeable batteries with enhanced terminal voltage
US 9673478, Lawrence Livermore National Laboratory

Planar high density sodium battery
US 9276294, Pacific Northwest National Laboratory

Polyoxometalate flow battery
US 9287578, Sandia National Laboratories

Lipon coatings for high voltage and high temperature Li-ion battery cathodes
US 9570748, Thomas Jefferson National Accelerator Facility and Oak Ridge National Laboratory



Patent No. 9287578

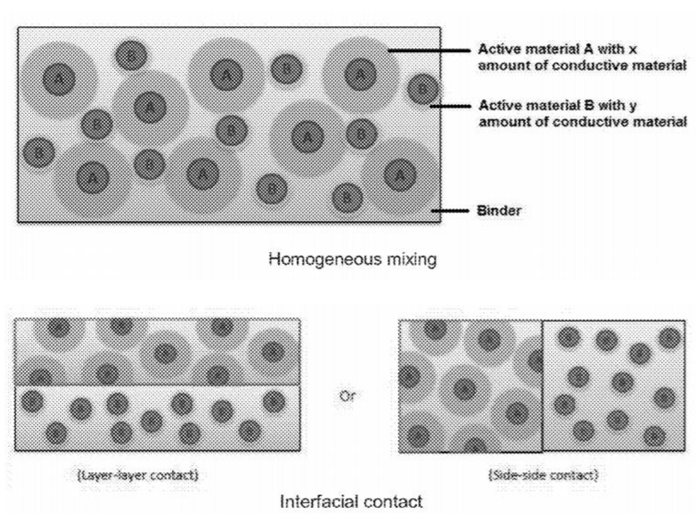
Batteries

Advanced separators based on aromatic polymer for high energy density lithium batteries
US 9598545, Argonne National Laboratory

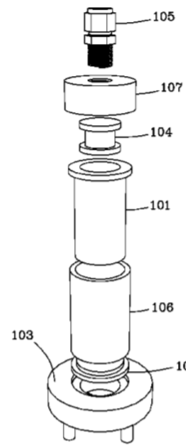
High-rate overcharge-protection separators for rechargeable lithium-ion batteries and the method of making the same
US 9525160, Lawrence Berkeley National Laboratory

Method of fabricating electrodes including high-capacity, binder-free anodes for lithium-ion batteries
US 9543054, National Renewable Energy Laboratory

Organometallic-inorganic hybrid electrodes for lithium-ion batteries
US 9444096, Thomas Jefferson National Accelerator Facility, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory



Patent No. 9444096



Patent No. 9444091

Cathodes

Hybrid radical energy storage device and method of making
US 9324992, National Renewable Energy Laboratory

Gradient porous electrode architectures for rechargeable metal-air batteries
US 9293772, Thomas Jefferson National Accelerator Facility and Oak Ridge National Laboratory

Apparatuses for making cathodes for high-temperature, rechargeable batteries
US 9444091, Thomas Jefferson National Accelerator Facility, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory

Electrolytes

Electrolytes comprising metal amide and metal chlorides for multivalent battery
US 9601801, Argonne National Laboratory

Means of introducing an analyte into liquid sampling atmospheric pressure glow discharge
US 9536725, Lawrence Berkeley National Laboratory and Pacific Northwest National Laboratory

Methods for separating particles and/or nucleic acids using isotachophoresis
US 9285340, Lawrence Livermore National Laboratory

Anti-perovskite solid electrolyte compositions
US 9246188, Los Alamos National Laboratory

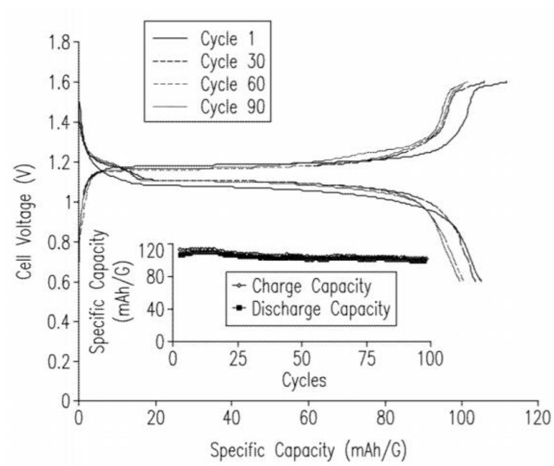
Electrochemical cell structure including an ionomeric barrier
US 9685684, Sandia National Laboratories

Magnesium-based energy storage systems and methods having improved electrolytes
US 9525191, Thomas Jefferson National Accelerator Facility, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory

Thermal Energy Storage

Nanoparticles for heat transfer and thermal energy storage
US 9080089, Argonne National Laboratory

Thermal energy storage apparatus, controllers and thermal energy storage control methods
US 9331483, Thomas Jefferson National Accelerator Facility, Pacific Northwest National Laboratory, and Oak Ridge National Laboratory



Patent No. 9525191

Laboratory Partnering Service (LPS)

For up-to-date and additional information on all DOE available technologies, visit: labpartnering.org/

Technology-to-Market Programs Strengthen the Innovation Ecosystem

Energy I-Corps: Relevant Project Teams

CellSage: Idaho National Laboratory (Cohort 4). CellSage is an advanced research and development software tool that facilitates more comprehensive battery characterizations as well as diagnostics and prognostics of aging mechanisms.

GeoCAES: National Renewable Energy Laboratory (Cohort 4). This novel technology helps to identify additional locations for compressed air energy storage and lower costs by repurposing depleted hydraulically fractured gas wells for air storage.

Polymer Membranes: Sandia National Laboratories (Cohort 2). Polymer membranes play a crucial function in many energy and water technologies, including energy storage. The prototype poly (phenylene)-based hydrocarbon membrane separators are being tested for use in real-world applications by system customers and partner research institutions.

For additional and up-to-date Energy I-Corps project teams and more information visit: energyicorps.energy.gov/

Energy I-Corps

Energy I-Corps pairs teams of researchers with industry mentors for an intensive two-month training where the researchers define technology value propositions, conduct customer discovery interviews, and develop viable market pathways for their technologies.

Energy I-Corps is managed by DOE's National Renewable Energy Laboratory, which leads curriculum development and execution, recruits program instructors and industry mentors, and assembles teams from the following national labs:

Technology Commercialization Fund

The Technology Commercialization Fund (TCF) leverages 0.9% of the Energy Department's annual budget for Applied Energy Research, Development, Demonstration, and Commercial Application to mature promising energy technologies with the potential for high impact.

The TCF helps businesses move promising technologies from DOE's National Laboratories to the marketplace. TCF projects receive at least an equal amount of non-federal funds to match the federal investment.

Select TCF Projects Relevant to Energy Storage

Earth Battery: Storing Energy with Compressed Air and Heated Brine in Porous Rock.
Lawrence Livermore National Laboratory.

Optimal, Reliable Building-Integrated Energy Storage.
National Renewable Energy Laboratory.

Low-Cost Battery Health Monitoring and Diagnosis System.
Pacific Northwest National Laboratory.

Evaluation of WattJoule's Vanadium Redox Flow Battery employing Sandia National Laboratories' membranes.
Sandia National Laboratories.

For additional and up-to-date TCF projects and more information visit: energy.gov/technologytransitions/services/technology-commercialization-fund

Learn More

Organizations may use several mechanisms to partner with the DOE National Laboratories in collaborative research and access the specialized capabilities of their facilities and experts.

The Office of Technology Transitions (OTT) engages with stakeholders, collects data, and evaluates impacts on DOE's partnering efforts. OTT uses this information to expand the commercial impacts of DOE research; implement the Energy Investor Center (EIC), the Technology Commercialization Fund (TCF), and Tech-to-Market initiatives; and streamline processes for partnering with the Labs.

Contact OTT to learn how to access technical experts, acquire the latest reports, identify promising energy projects, and locate DOE-funded technologies.

Email:
OfficeofTechnologyTransitions@hq.doe.gov

Website:
energy.gov/technologytransitions

Energy Investor Center (EIC)

The mission of the EIC, within OTT, is furtherance of America's technology leadership and economic competitiveness through targeted market engagement and commercialization of DOE's innovation portfolio. The EIC enables more and smoother technology hand-offs from the DOE Labs to market actors, as well as expanding the pool of potential capital providers to support these commercialization pathways.

- **Laboratory Partnering Service (LPS):**
  LPS is an online platform that enables public access to world-leading DOE National Laboratory energy experts, project marketing summaries, and licensing opportunities.
- **Laboratory-Investor Knowledge Series (LINKS):**
  EIC coordinates stakeholder meetings to connect DOE National Lab experts and technology program managers with investors to discuss market needs, DOE technology offerings, and resulting partnership opportunities.
- **Public Private Partnerships:**
  EIC works with market actors and investors to facilitate targeted partnerships with DOE Labs and Programs that maximize the nation's return on investment in the DOE innovation portfolio.

For more information visit: energy.gov/technologytransitions/eic

DOE-Led Webinars on Energy Storage

DOE and the National Labs often host webinars on many topics in Energy Storage. All past webinars are recorded and available on the internet.

To learn more about challenges, solutions, research areas, and technologies available for commercialization, visit: energy.gov/technologytransitions/eswebinars

Joint Center for Energy Storage Research, jcesr.org/scientific-tools/electrochemical-discovery-laboratory/

Energy Storage Success Stories

U.S. Department of Energy

Contents

U.S. DEPARTMENT OF ENERGY

Office of Technology Transitions

The Office of Technology Transitions develops DOE's policy and vision for expanding the commercial impacts of its research investments and streamlines information and access to DOE's National Labs, sites, and facilities to foster partnerships that will move innovations from the labs into the marketplace.

Acoustical Approach to Battery Diagnostics

ARPA-E and Lawrence Berkeley National Laboratory in partnership with Feasible

Soundwaves offer a quick, non-invasive, low-cost way to assess battery status and service.

Innovation

Traditional battery diagnostics are either slow, expensive, invasive, inaccurate, or possess some mix of those drawbacks. Ultrasonic analysis, in contrast, is inherently fast, noninvasive, sensitive, scalable, and offers direct and detailed information about their internal components and physical structure.

Outcomes

Technology Advancement

Berkeley Entrepreneurship Program researchers had invented an acoustic interrogation method which determines the state of charge and health, and physical structure for any battery format. Their novel approach improves battery development and quality control efficiencies by linking cell performance directly to internal structure—a previously unavailable option. Uniquely, this technique identifies individual internal flaws which can often dominate performance limitations, whereas existing electrochemical methods do not. Developers collaborated with Berkeley Lab to adapt this capability to the needs of both battery R&D labs and manufacturers.

Impact

Over the next three years, development of reliable control algorithms and reduced hardware costs could enable broad implementation of these sensors into manufacturing lines to overcome yield limitations, and into battery management systems for stationary storage and large device applications. Longer term, the hardware may shrink to the size of microelectromechanical systems and become an integral part of the architecture in every cell and system.

This technology may also support the emerging market for recycled cells in stationary markets by reducing the significant barrier of the uncertainty of an EV battery's remaining useful life. The higher testing throughput enhances this basic paradigm. According to Navigant Research, this $16M recycled cell market is projected to grow to $3B by 2035.[1]

Barry Van Tassell (left) and Andrew Hsieh (right), founders of Feasible, at LBNL. [cyclotronroad.org/journal/2017/12/4/feasible-arpa-e]

"How sound moves through a battery indicates important things about the battery's internal structure. It can show the level of charge and also how old the battery is and what has happened to it over its lifespan."[2]

Daniel Steingart,
Assistant Professor, Princeton

Timeline[2]

April 2015: Proof of concept paper published

October 2015: ARPA-E IDEAS grant awarded to further explore acoustic method[3]

January 2016: Feasible participates in UC Berkeley's LAUNCH 2016 Startup Accelerator

March 2016: Feasible joins Cyclotron Road, a technology innovation incubator at Berkeley Lab[4]

July 2016: Feasible wins an NSF SBIR Phase I award

August 2017: Feasible is awarded funding through the ARPA-E AMPED Program to continue developing its acoustic diagnostic technology

[1] Report. pdfs.semanticscholar.org/7641/fad087917b51afab532ffd5a3472ff6623a9.pdf

[2] Feasible. feasible.io/news/

[3] ARPA-E IDEAS. arpa-e.energy.gov/?q=slick-sheet-project/acoustic-analysis-battery-testing

[4] Cyclotron Road. cyclotronroad.org/feasible/

Advanced Battery Manufacturing

Loan Programs Office in partnership with Nissan North America

Scaling up domestic advanced battery manufacturing for electric vehicles

Innovation

In January 2010, LPO closed an ATVM loan to Nissan North America, Inc. to manufacture its all-electric LEAF vehicle, including associated battery packs and electric motors. By taking advantage of the competitive rates offered by the ATVM program, Nissan was able to "onshore" its production of the LEAF for the North American market.

Outcomes

Technology Advancement

The loan to Nissan was used to construct and equip one of the largest advanced battery manufacturing plants in the United States, to retool its Smyrna, Tennessee manufacturing facility for assembly of the LEAF, and to construct an efficient and environmentally friendly paint plant. Nissan also used the loan to develop an electric powertrain production line for the LEAF vehicle within its engine manufacturing facility in Decherd, Tennessee. Its state-of-the-art manufacturing plant was designed with a production capacity of up to 4.4 gigawatt-hours' worth of battery packs.

Impact

The ATVM loan has helped to support 1,300 jobs. In 2014, the LEAF became the top-selling electric plug-in vehicle in the United States and by 2018, nearly 115,000 LEAFs had been sold in the United States. Nissan fully repaid the loan in 2017.

Manufacture of battery before inclusion in Nissan LEAF.

[Photo: Nissan North America]

The sale of the battery plant "is expected to enable the battery business to utilize GSR's wide networks and proactive investment to expand its customer base and further increase its competitiveness."

Brian Brockman,
Spokesperson, Nissan North America

Timeline

2010: DOE closes on Nissan loan

2012: Advanced battery production starts

2017: Nissan repays loan in full

[1] Daily News Journal. dnj.com/story/news/2017/10/10/nissan-smyrna-battery-plant-expand/750204001/

Advanced Membranes for Next-Generation Batteries

Lawrence Berkeley National Laboratory in partnership with Sepion Technologies

Sub-nanometer porous polymer membranes bring longer life to batteries powering electric mobility.

Innovation

LBNL researchers developed a platform technology for highly conductive battery membranes with high transport selectivity. The sub-nanometer pores of the polymer membranes are large enough for the battery's ions to cross the membrane, but small enough to block the battery's active materials from moving between the electrodes. Such membranes extend the cycle life of batteries in use today and revitalize battery chemistries that were previously discarded due to lack of a suitable membrane. LBNL researchers founded Sepion Technologies in 2015 to commercialize the membrane technology for next-generation batteries for electric mobility and long-duration energy storage for grid modernization.

Outcomes

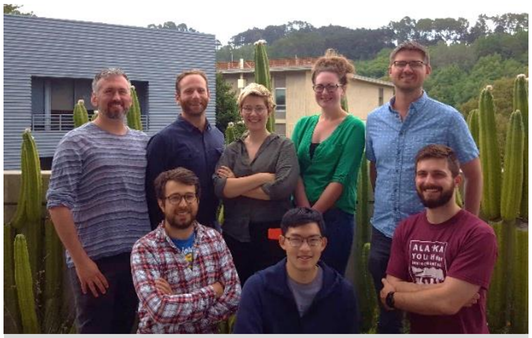
Technology Advancement

Separators used in today's lithium-ion and lithium-metal batteries are typically non-selective porous polyolefins, which place limits on anode performance due to crossover-related surface reactions. Using LBNL's ion-selective membrane technology, graphite and lithium anodes are chemically and dimensionally stabilized, which increases their lifetime and prospects for safe operation. These membranes are compatible with broad palette of cathode chemistries and electrolytes used for EVs, electrified flight, and grid-scale energy storage.

Through user agreements with LBNL's user facilities and CRADAs with LBNL and ANL, Sepion continues to develop the membrane for target markets. The startup is building a pilot manufacturing line to produce rolls of both membranes and membrane–electrode sub-assemblies for batteries.

Impact

Sepion views LBNL's drop-in membrane technology as a means to immediately boost the energy density of batteries by 30% for the same capital expenditure, which significantly increasing the return-on-investment for battery manufacturers. The extended lifetime of those cells is a differentiator for original equipment manufacturers in the market as well.



Staff Scientist Brett A. Helms (left) led the team at LBNL to advance sub-nanometer porous polymers as ion selective membranes, which are now being commercialized by Sepion Technologies.

[Photo: LBNL]

"Batteries are central to our sustainable future but require innovative materials to truly unlock their potential for impact."

Dr. Peter Frischmann,
CEO, Sepion Technologies

Timeline

2015: LBNL researchers and collaborators in JCESR discover new membrane technology for EV and grid batteries

2015: LBNL researchers form startup Sepion Technologies

2016: LBNL's membrane technology wins R&D 100 Award[1]

2016: Sepion Technologies and LBNL receive $150k Phase 1 DOE STTR grant

2017-2018: Sepion wins subaward as partner on ARPA-E IONICS project with 24M; Sepion receives a Phase 2 DOE STTR grant and a grant through DOE's HPC4mfg for membrane development

2018: Technology is licensed to Sepion Technologies for commercialization

[1] Cyclotron Road. cyclotronroad.org/sepion/

Advanced Vanadium Flow Battery

Office of Electricity and Pacific Northwest National Laboratory in partnership with UniEnergy Technologies, Avista Utilities, and the State of Washington

Award-winning vanadium flow battery technology developed by DOE lab and commercialized by the private sector. A 1 MW, 3.2 MWh system of this battery type was deployed in Pullman, WA by Avista Utilities.

Innovation

Researchers at the Pacific Northwest National Laboratory (PNNL) significantly advanced the performance of redox flow batteries, which hold great promise for storing large amounts of renewable energy and providing greater stability to the energy grid. This endeavor was partially funded by the Office of Electricity.

The work lifts persistent limitations on the technology in the areas of cost, feasible temperature ranges, and energy density. Under a licensing agreement, UniEnergy Technologies LLC (UET) will continue to develop and commercialize the battery technology. The battery was more recently selected to be included in a 1 MW, 3.2 MWh demonstration in Pullman, WA.

Outcomes

Technology Advancement

The technology uses an electrolyte chemistry developed by PNNL. The mixed-acid vanadium electrolyte can store 70% more energy and operates at higher temperatures than conventional vanadium electrolytes. The batteries also offer a lower total cost of ownership than batteries that use other chemistries, such as lithium-ion batteries.

Impact

Storage systems developed with the mixed-acid vanadium electrolyte offer a service life of over 20 years without degrading power or energy capacity. The electrolyte is nearly 100% recyclable and completely non-flammable.

UET batteries are fully integrated with power electronics and controls, facilitating rapid use of the energy storage system by utilities, independent power producers, microgrids, and commercial and industrial customers. The licensing agreement will lead to enhanced commercial products that enable the grid to operate more reliably and efficiently.

Snohomish PUD's flow battery system housed in shipping containers. Batteries manufactured by UniEnergy Technologies.
[Image: Snohomish PUD]

"The redox flow battery is well-suited for storing intermittent renewable energy on the electricity grid. The technology can help balance supply and demand, prevent disruptions, and meet the grid's varying load requirements."[1]

Imre Gyuk
Energy Storage Program Manager
DOE Office of Electricity

Timeline

Oct. 2012: PNNL technology licensed by UniEnergy Technologies

2015-2017: Large-scale demonstration in Washington state is world's largest containerized flow battery system

June 2017: More than 14 MW of UET flow batteries installed and another 155 MW ordered for utilities and industry

June 2017: UniEnergy Technologies wins the EPA Green Chemistry Award.

[1] PNNL: pnnl.gov/news/release.aspx?id=945
[2] OSTI: osti.gov/biblio/1214115-hybrid-energy-storage-systems-utilizing-redox-active-organic-compounds
[3] OSTI: osti.gov/biblio/1257193-iron-sulfide-redox-flow-batteries

Austin Energy (SHINES)

Solar Energy Technologies Office in partnership with Austin Energy

The Austin Sustainable and Holistic Integration of Energy Storage and Solar PV (SHINES) program integrates more than 3 MW of distributed energy storage with 31 smart inverters and includes more than 700 PV customers.

Innovation

The Austin SHINES project is meant to demonstrate a system that is adaptable to any part of the country. The distributed energy resource (DER) system will advance toward a levelized cost of energy (LCOE) of 14 cents per kWh for solar energy when bolstered by energy storage and DER management options. The lead for this project is Austin Energy, the 8th largest public utility in the United States. This project was supported with by the Department of Energy Solar Energy Technologies Office.

Outcomes

Technology Advancement

Austin Energy has created a management platform that allows for the coordination of distributed solar photovoltaic and battery storage systems at multiple residential, commercial, and utility-scale sites within the distribution network. By operating these resources as a coordinated system, Austin Energy can enable a high penetration of renewable energy while reducing the overall cost to serve load. Austin Energy has also integrated smart inverters into its network allowing for the autonomous management of distributed energy resources.

Impact

Outcomes include the creation of new DER control methodologies deployable within a utility-grade software platform, optimal design methodologies for individual DER installations, a comparison of multiple DER aggregation and ownership methodologies (including direct utility control, third-party aggregator, and autonomous), and a comparison of multiple DER technology configurations. Because the outcomes of this project will be based on actual large-scale PV and storage deployments and operation experiences, the project will provide insight on which technologies will serve energy loads at low costs and high penetrations of solar.

Residential PV portion of the Austin Energy distributed energy resource system.
[Photo: Austin Energy]

"All progressive utilities are moving toward a future where [energy production] is a two-way street. The way we're looking at it is that some of our customers have power generation capacity [through solar panels], so what can we add to the mix? Well, we can add batteries, a grid, and substations. Our goal is to figure out as we move from one model to another model: How do we increase value for our customers?" [1]

Robert Cullick
Spokesperson, Austin Energy

Timeline

2016: SHINES awardees announced including $4.3 million for Austin Energy

2016: Project kick-off

2018: Austin Energy wins the 2018 Grid Edge Innovation Award from Greentech Media

[1] Austin Chronicle: austinchronicle.com/news/2017-06-23/austin-energy-partnership-helps-reach-renewable-energy-goals/

Battery Cathode for Plug-in Electric Vehicles (PEVs)

EERE Vehicle Technologies Office with Argonne National Laboratory in partnership with LG Chem

Research at Argonne National Laboratory produced a cathode material that improves the safety and range of lithium-ion plug-in electric vehicles. The technology is now used in commercial PEVs such as the Chevrolet Volt.

Innovation

The cathode material in lithium-ion batteries can use a number of different chemistries to deliver distinct properties for the electric vehicle. Nickel-manganese-cobalt cathodes developed by ANL were shown to lower costs, reduce overheating, and deliver higher energy capacity relative to prior chemistries.

The cathode technology was supported by VTO and subsequently licensed by ANL to BASF, LG Chem, General Motors, Envia, and TODA.

Outcomes

Technology Advancement

The new cathode material incorporates nickel, manganese, and cobalt. The use of manganese-rich materials improves cathode stability and raises the charging limit to 4.6 volts, which is higher than that of most contemporary EV batteries.

Impact

Higher-capacity batteries enable electric vehicles to use either fewer batteries per vehicle to lower the cost or more batteries to extend the range. This novel cathode material increases energy storage capacity 50–100% over traditional materials. These batteries are less likely to overheat and more affordable because they use manganese.

LG Chem further improved this chemistry for the next-generation Volt, which has a 39% higher all-electric driving range using fewer battery cells. Experts forecast cathodes using nickel-manganese-cobalt oxide chemistry will soon replace today's commercially used cobalt oxides and nickel-cobalt-aluminum oxides in EV and electronic applications.[1]

Replica of T-shaped battery used by Chevy Volt.
[Photo: General Motors]

"This battery technology is a step toward energy independence for the U.S.; it helps create jobs, and it can have a positive impact on the environment." [3]

Jeff Chamberlain, Argonne
Battery Research and Development

Timeline

Late 1990s: DOE Office of Science funds intensive study on lithium-ion batteries

2002: VTO supports ANL research to develop new cathode for Li-ion PEV batteries

2010: Novel cathode completed

2011: LG Chem Ltd. licenses the technology

2011-2015: The original and next-gen Volt and the Ford Focus EV use this technology[3]

[1] IP Tech Blog: iptechblog.com/2016/12/basf-wins-big-in-battery-battle/

[2] EERE Success Story: energy.gov/eere/ success-stories/articles/eere-success-story-battery-cathode-developed-argonne-powers-plug

[3] ANL: anl.gov/articles/argonne-battery-technology-helps-power-chevy-volt

U.S. DEPARTMENT OF ENERGY | Office of TECHNOLOGY TRANSITIONS

Battery Diagnostic Software

EERE Vehicle Technologies Office and DOE’s Lab-Corps (now Energy I-Corps) program at Idaho National Laboratory

Software tool enhances understanding of how batteries are affected by use, enabling better matching to specific applications.

Innovation

A researcher at DOE's Idaho National Laboratory developed an advanced software diagnostic tool to assess batteries currently in use. Known as CellSage (or Cell’s Age), this technology can characterize battery performance, diagnose the health of a battery, and predict how much longer it will be able to function under specific conditions or scenarios.

The software was developed with funding from the U.S. Department of Energy at the Idaho National Laboratory.

Outcomes

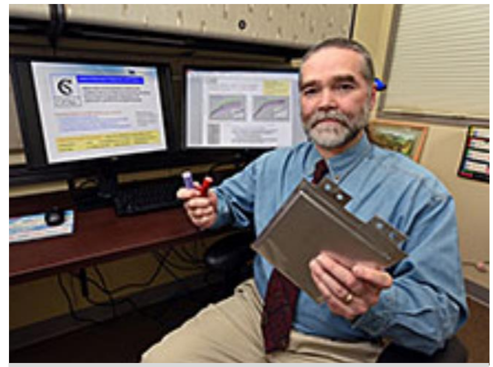
Technology Advancement

Regarding the cell as a batch reactor permits consideration of multiple aging parameters in an efficient mathematical framework. Cell performance data over time, plus robust interpretations by algorithms, support early diagnosis, predictive analyses, and improved batt ery design. The software provides insight into battery health, including kinetic performance, conductance fade, capacity loss, power loss, and ancillary quantities. It analyzes at least 10 environmental and operational parameters and generates more than 20 specific outputs, providing realistic and accurate life cycle predictions.

To study a known Li-ion battery chemistry for electric vehicle applications, the software analyzes the cycling protocol, geographic location and aspects of battery thermal management. To ensure the battery is correctly matched to the application, users can fine tune the simulation by location, cycling protocols, battery chemistries, and thermal management parameters.

Impact

The tool is expanding understanding of how specific battery chemistries react to usage conditions and environments. For example, the software can be used to predict geographic-dependent battery aging in order to optimize battery pack designs to increase performance and reduce cost.



INL researcher Kevin Gering developed CellSage to diagnose battery health.
[Image: INL]

“DOE’s Lab-Corps program offers a new pathway to advance greater collaboration between industry and national laboratories.”

Steven Aumeier, Director,
Center for Advanced Energy Studies

Timeline[1]

2002-2014: With support from the EERE Vehicle Technologies Office, INL researchers develop a method for measuring the capacity loss and performance degradation in rechargeable batteries.

2015: INL researchers develop a computer model for characterizing, screening, and optimizing electrolyte systems

2016: CellSage selected for Lab-Corps program to further develop the model using INL expertise in thermodynamics and the chemical kinetics of degradation reactions

2017: Ridgetop Group, Inc., executes patent and copyright license to commercialize battery lifecycle assessment tool based on the CellSage technology[2]

[1] Publications. osti.gov/search/author:Gering,%20Kevin%20L.

[2] Source: ridgetopgroup.com/wp-content/uploads/CellSage-Document.pdf

Borrego Springs MicroGrid

Office of Electricity in partnership with San Diego Gas & Electric (SDGE)

This demonstration project provides a proof-of-concept for using information technologies and distributed energy resources (primarily solar PV and batteries) to increase utility asset utilization and reliability.

Innovation

A small-scale distributed generation system or microgrid has been demonstrated to increase asset utilization and power reliability for an isolated residential population of 2,800. Borrego Springs is served by a 60-mile transmission line subject to wildfire, windstorms, flooding, and extreme temperatures. The microgrid incorporates diesel generators, solar power, batteries, and control systems. Demonstrating the real-world operation of the control systems incorporated in this microgrid supports their future scale up for use in larger systems.

Outcomes

Technology Advancement

This microgrid operates an installed capacity of around 4 MW with two 1.8 MW diesel generators, a larger 1500 kWh battery, three 50 kWh batteries, six 8 kWh home storage units, and 700 kW of rooftop solar photovoltaic power. The microgrid also monitors 125 residential home network systems.

The control systems tested on the system include volt-ampere-reactive (VAR) management, supervisory data acquisition (SCADA), feeder automation system technologies (FAST), outage management systems (OMS), and advanced metering infrastructure (AMI).

Impact

Understanding the systems integration and management of a microgrid at pilot scale enables more and larger-scale projects. Findings from this project will help stabilize future microgrids.

This project demonstrated the capability to use automated distribution controls, improve the capacity of the feeder/ substation, and increase visibility into microgrid operations. Severe conditions at this pilot site point to need for continued system enhancements to provide seamless reliability during extreme events that coincide with reduced solar insolation.

Distributed residential storage for the Borrego Spring MicroGrid—the first of its kind to power an entire community with renewable energy.
[Photo: Berkeley Lab]

"As a result of the wildfires, we decided…to rethink the way we serve communities such as Borrego Springs. We started our quest for designing a fully-integrated microgrid."[1]
James Avery
SDGE Senior VP for Power Supply

Timeline

Nov. 2011: Demonstrate integration of existing distributed generation and VAR

Sept. 2012: Integrate OMS for microgrid

Oct. 2012: Demonstrate integration of advanced energy storage

Feb. 2013: Integrate price-driven load management

Mar. 2013: Begin functionality tests for integrating FAST systems[2]

2014: Microgrid helps avoid small outages

2015: CEC grant enables interconnect with nearby 26-MW solar facility

[1] Utility Dive. utilitydive.com/news/inside-the-nations-first-renewables-plus-storage-microgrid/401476/

[2] DOE Fact Sheet. smartgrid.gov/files/NT02870_RDSI_Fact_Sheet_SDGE_Borrego_3.0.pdf

Conducting Polymer Binder for High-Capacity Li-Ion Batteries

EERE Vehicle Technologies Office and Lawrence Berkeley National Laboratory in partnership with Nextval, Inc.

Novel binder material facilitates use of silicon in anode material, potentially enabling smaller, lighter, and cheaper high-capacity lithium-ion batteries.

Innovation

This conducting polymer binder delivers key capacity benefits and solves some of the durability issues associated with using silicon as the anode material in lithium-ion (Li-ion) batteries. The theoretical specific capacity of silicon is at least 10 times that of graphite, the traditional anode material for batteries. Until now, this capacity also stressed the material to such an extent that its structural integrity and performance deteriorated rapidly.

Lawrence Berkeley National Laboratory received funding from DOE's Vehicle Technologies Office (VTO) to support the development of this technology, which received the R&D 100 Award in 2013.

Outcomes

Technology Advancement

The flexible, elastic binder material of this anode is able to handle the expansion and contraction experienced during charging and discharging cycles, protecting the stability of the anode structure and making the battery lifecycle comparable to that of traditional lithium-ion batteries.

Impact

This material increases battery storage capacity 30% over traditional lithium-ion materials—far above the average annual capacity increases seen over past decade. In addition, this material increases cycle and life stability.

This anode is compatible with current manufacturing technologies. As a result, it should be able to be used in existing manufacturing plants to reduce the cost of rechargeable batteries. LBNL has made the technology available for licensing.[1]

Adhesive polymer binder before being blended with silicon in a slurry process to form improved anode material for Li-ion batteries. [Photo: Berkeley Lab]

The elastic material stretches during the expansion of silicon particles as the battery charges and contracts during discharge—giving silicon anodes the flexibility to "breathe." The electronically conductive binder for silicon anodes triples the energy of current graphite anodes with much improved cycle life.[2]

Timeline

2010: Project starts

2012: Project completed

2013: Receives 2013 R&D 100 Award

2014-2016: LBNL develops second and third generations to optimize functionality of conductive polymer binders in Si-based systems [3]

[1] LBL.gov eta.lbl.gov/news/article/56381/better-batteries-with-a-conducting-polymer-binder

[2] EERE. energy.gov/eere/success-stories/articles/eere-success-story-california-conducting-polymer-binder-boosts-storage

[3] Energy.Gov energy.gov/sites/prod/files/2015/06/f23/es223_liu_2015_o.pdf

Cost-Effective Process for Extracting Lithium from Natural Brines

National Energy Technology Laboratory

This novel process significantly reduces the overall cost, time, and energy needed to extract lithium from geothermal brines for use in clean energy technology.

Innovation

The United States relies heavily on lithium (Li) to manufacture advanced clean energy technologies like fuel cells and electric vehicles. The National Energy Technology Laboratory (NETL) has developed a two-step process for extracting Li from natural brines (naturally heated hydrothermal fluids beneath the earth's surface) and using them to generate lithium carbonate (Li_2CO_3), an industrially useful product.[1]

Outcomes

Technology Advancement

The method uses a unique carbon pressure-based process to first concentrate Li as ions in the brine solution and then extract Li as Li_2CO_3 through the application of CO_2 gas to the concentrated brine under predetermined conditions.

Impact

This new technology could replace the conventional multi-step method, which requires a series of football field-sized evaporation ponds and lengthy acid/base leaching processes—often taking 18–24 months to produce Li compounds such as (Li2CO3), lithium chloride, and lithium hydroxide.

The process uses CO_2 as the only additive—which can be sourced from other industrial waste streams—significantly reducing processing time and energy requirements. Process can also be fully implemented at the brine source using existing geothermal technologies, eliminating the need for transportation or concentration of brines. In addition to reducing U.S. dependence on foreign Li sources, the process yields useful byproducts (sodium chloride, calcium carbonate, etc.). The process could be applied to Li extraction from seawater or the extraction of other important elements.

The Salton Sea region is currently one of North America's prime sources of lithium.
[Photo: Pure Energy]

Growing global demand for cell phones, electric cars, and other products relies on a continuous supply of the lightest metal: lithium.

Timeline

2017: U.S. Non-provisional Patent application filed October 10, 2017

[1] NETL. netl.doe.gov/business/tech-transfer/available-technologies/tech-details?id=aaee2bae-fbf6-4a67-8685-9bd3d9dd386d

Crescent Dunes Solar Energy Plant

Loan Programs Office and Solar Energy Technologies Office in partnership with SolarReserve

This multi-year effort resulted in the first commercial solar power tower project in the U.S. to use molten salts to store solar energy, making it available to the grid during peak energy demand periods.

Innovation

The Crescent Dunes Solar Energy Plant uses concentrating solar power (CSP) and molten salt thermal storage to deliver 100% renewable baseload power generation to 75,000 homes in Nevada. This project utilizes 90% of the solar energy that it receives, and the lead was SolarReserve, a company formed in 2008 for the purpose of commercializing research work supported by SETO. This project was supported with research grants from the DOE SETO, by seed capital from the investment firm U.S. Renewables Group, and by financing from the Energy Department's Loan Programs Office.

Outcomes

Technology Advancement

The CSP plant works by reflecting light from over 10,000 heliostats (over 1 million m^2 mirror surface) at a central receiver mounted on top of a tower. This tower heats molten salt which is circulated through the tower before it is used to generate steam and power like traditional power plants. Unlike photovoltaic (PV) solar power, this CSP design is built to address intermittency issues by heating 70 million pounds of salt to a maximum temperature of 1,050°F at the tower. The salt provides energy storage by preserving thermal energy for use at a later time. The Crescent Dunes CSP plant adds 110 MW with over 10 hours of storage capacity equating to more than 1.1 GWh of stored energy available to the grid.

Impact

The plant has already paved the way for future cost declines and enabled the company to bid for new CSP projects at even lower electricity prices. A milestone for the country's energy future, the Crescent Dunes establishes the United States as a global leader in CSP technology. Crescent Dunes serves as a blueprint for solar projects in Latin America, Africa, the Middle East, and Asia, helping countries around the world use clean, affordable electricity.

Crescent Dunes concentrating solar power plant with central tower heated by reflected light

[Photo: Solar Reserve]

"It's really an alternative to fossil fuel or even nuclear. You couldn't power a city with just PV and wind, but you could with CSP, because of the storage capacity." [1]

Kevin Smith
CEO, SolarReserve

Timeline

1994: Rocketdyne, the parent company of SolarReserve, receives a SETO grant to build 'Solar Two' a pilot molten salt receiver

1999: Solar Two successfully completes its operation, proving the technological feasibility of molten salt systems for thermal energy storage

2008: A new company, SolarReserve, is formed to commercialize the molten salt technology

2011: SolarReserve receives financing from the DOE Loan Programs Office to begin the construction of Crescent Dunes.

2012: SolarReserve and Rocketdyne finalize the design for a new heliostat control system with 10 times more capacity than the version utilized in the Solar Two plant

2015: The Crescent Dunes Solar Energy Plant reaches commercial operation.

[1] Business Insider: businessinsider.com/solar-power-towers-in-nevada-desert-2016-8

Falling Particle Receiver for Concentrated Solar Energy

Sandia National Laboratory as part of the SunShot National Laboratory Multi-year Partnership (SuNLaMP)

Novel design for concentrating solar power captures and stores the heat in sand-like ceramic particles to take advantage of their higher potential temperature relative to molten salt—improving efficiency and lowering cost.

Innovation

Sand-like ceramic particles, known as proppant, are more efficient at capturing and storing heat than the molten salts used in other concentrating solar power (CSP) systems. The use of proppant can increase the efficiency of CSP systems and lower the cost of the generated electricity. Researchers designed a falling-particle receiver that moves the proppant past the intensely concentrated sunlight beam to capture and store the heat. The particles can be stored in an insulated tank to generate power several hours later. Alternatively, the particles can heat a secondary working fluid for the power cycle.

Outcomes

Technology Advancement

This project achieved an average outlet temperature above 700°C and thermal efficiencies between 70% and 80%. Molten salts, in contrast, cannot achieve temperatures above 600°C and have power-cycle efficiencies of about 40%. Proppant particles falling through the concentrated solar beam have the potential to reach temperatures greater than 1,000°C.

Next steps include scaling-up the system to greater than 10 MW and reducing the volume of particles lost.

Impact

Reducing the cost of electricity from CSP can make the technology cost competitive with other sources. The built-in storage of the system provides an additional benefit. In the United States alone, between 11 and 21 gigawatts of CSP could be integrated into existing fossil fuel plants—enough electricity to power between 3 million and 6 million homes.

Falling Particle Receiver installed at the National Solar Thermal Test Facility at Sandia National Lab to evaluate proppant (sand-like ceramic particles) as the heat storage medium.
[Photo: National Solar Thermal Test Facility]

"This technology will enable higher temperatures and higher-efficiency power cycles that will bring down the cost of electricity produced from CSP. In addition, the ability to cheaply and efficiently store thermal energy directly in the heated particles will enable power production at night and on cloudy days."[1]

Cliff Ho
Principal Project Investigator

Timeline

2012: Project begins

2015: Testing at National Solar Thermal Test Facility

2016: Project receives 2016 R&D 100 Award

2016-2018: Receives new DOE funding to explore particle/sCO_2 heat exchanger and novel particle curtain designs

2018: New DOE award extends R&D on high-temperature components, integrated assemblies, and systems testing

[1] Sandia: energy.sandia.gov/sandias-continuously-recirculating-falling-particle-receiver-emplaced-at-top-of-solar-tower/

Graphene Material to Reduce Battery Charge Time

Office of Basic Energy Sciences and Pacific Northwest National Laboratory in partnership with Vorbeck Materials and Princeton University

An award-winning scientific advancement could improve the performance of batteries for vehicles and consumer electronics.

Innovation

Researchers at the Pacific Northwest National laboratory (PNNL), Princeton University, and Vorbeck Materials created a new, graphene-infused material that may lead to a higher-performing battery for vehicles and consumer electronics.

The ultimate goal is to create a battery that enables electronic devices and power tools to recharge in minutes rather than hours, or function as part of a hybrid battery system to enable fast longer range and fast charge of electric vehicles.

Outcomes

Technology Advancement

With new insights about material interactions, PNNL and Princeton University showed that small quantities of high-quality graphene could dramatically improve the power and cycling stability of lithium-ion batteries, while maintaining high-energy storage.

Researchers created 3D nanostructures for battery electrodes, using lithium metal with thin films made of Vorbeck's patented graphene material, or composite materials containing the graphene materials. The unique properties of graphene, combined with chemical modification of the graphene and assembly into novel structures, improves the conductivity and controls undesirable surface reactions on lithium. The resulting battery material has the potential to store large amounts of energy and recharge quickly.

Impact

Rechargeable lithium-ion batteries are widely used in electronic devices such as laptops and smartphones, in medical devices, and in power tools and electric vehicles. A successful commercial product based on this technology could enable greater use of electric vehicles and charge consumer electronics faster.

A new material that incorporates graphene technology could extend the life of batteries and accelerate charging time.
[Image: PNNL]

"The pioneering work done by Vorbeck, Princeton University, and PNNL is leading to the development of batteries that recharge quickly, reducing the time it takes to charge a smartphone to minutes and an electric vehicle to just a couple of hours."

John Lettow, President
Vorbeck Materials

Timeline

2010: Vorbeck Materials and PNNL begin working on battery electrodes under a CRADA

2012: First patent granted

2012-2015: Vorbeck Materials and PNNL received support from ARPA-E to further develop the electrode's materials

2012: Vorbeck Materials is named one of three nationwide winners of DOE's "America's Next Top Energy Innovator" challenge

2013: Vorbeck licenses PNNL technology

2013-Present: A portfolio of >13 US patents and >8 foreign patents were granted and licensed.

PNNL: pnnl.gov/news/release.aspx?id=968

OSTI: osti.gov/biblio/1211223-manipulating-surface-reactions-lithium-sulphur-batteries-using-hybrid-anode-structures

OSTI: osti.gov/biblio/1052509-functionalized-graphene-sheets-molecular-templates-controlled-nucleation-self-assembly-metal-oxide-graphene-nanocomposites

Grid-Scale Flywheel Energy Storage Plant

Office of Electricity in partnership with Hazle Spindle LLC and Beacon Power

20-MW frequency regulation plant made up of 200 separate flywheels is able to respond to 97% of requests at a speed of less than 4 seconds per request.

Innovation

While basic flywheel technology has been used for centuries, large, economically viable, flywheel-based power frequency regulation facilities are rare. Located on the PJM interconnection, this flywheel project employs lessons learned from previous projects to introduce technologically advanced flywheels at lower installation cost.[1]

Outcomes

Technology Advancement

These highly durable flywheel systems can last more than 20 years. They can achieve 100% depth of discharge for more than 150,000 cycles without degrading over time. The flywheels are housed in 20 1-MW pods, each of which contains 10 flywheels and the associated electronics.

A separate control module monitors the vibrations, temperatures, and other critical criteria for operation. Each flywheel has a 100-kW rating with 25 kWh of power.

Impact

Frequency regulation technologies like flywheels help improve grid reliability by reducing frequency swings caused by rapid changes in supply and demand (generation and load). When generated power exceeds load, the flywheels store the excess energy. When load increases, the flywheels return the energy to the grid. These technologies can respond to signals over 100 times faster than traditional technologies.

This system demonstrated an availability of 98% over the performance period and provided the frequency regulation required by PJM. In addition, the project lowered the amount of CO_2 and other air emissions in the control area and reduced the cost of frequency regulation.

[1] In August 2010, a similar flywheel energy storage project in Stephentown, NY was funded by the Loan Programs Office. The lessons learned from Stephentown project were used to advance the technology for the Hazle project.

20-MW flywheel facility in Hazle, Pennsylvania

[Image: Smartgrid.gov]

"PJM continues to welcome new technologies that provide diversity to the asset mix in PJM, as well as an opportunity to provide frequency regulation service. This will be the first flywheel technology placed into our regulation market."[2]

Terry Boston
CEO and President, PJM Interconnection

Timeline

Dec. 2012: Site Construction begins

Sept. 2013: Plant commences operation

Nov. 2013: Site construction complete

July 2014: Plant achieves full capacity and meets operational goals[3]

2015: Project contributes to improvements in operations, storage devices, system controls, and balance of plant[4]

2018: Beacon acquired by RGA Investments; Beacon maintains plants in Stephentown, NY and Hazle, PA[5]

[2] Fact sheet: smartgrid.gov/files/Hazle_Spindle_Spinning-Solution-Momentary-Electric-Grid-Disturbances.pdf

[3] Source: smartgrid.gov/files/OE0000200_HazleSpindle_FactSheet.pdf

[4] Briefing: sandia.gov/ess/docs/pr_conferences/2014/Thursday/Session7/02_Areseneaux_Jim_20MW_Flywheel_Energy_Storage_Plant_140918.pdf

[5] Source: rgalabs.com/BeaconPressRelease2018May01.pdf

Impedance Measurement Box for Battery Health Diagnostics

EERE Vehicle Technologies Office and Idaho National Laboratory in partnership with Dynexus Technology

Wideband impedance technology analyzes the health and safety of advanced energy storage devices.

Innovation

A wideband impedance technique developed at INL delivers in-depth diagnostic insights not previously available outside the battery research lab. A set of algorithms analyzes a battery's response to an input signal composed of a wideband set comprised of about 25 to 30 sine waves.[1]

The technology was invented collaboratively by researchers from INL's Energy Storage Group, Montana Tech of the University of Montana, Motloch Consulting, and Qualtech Systems, Inc., with support from the Vehicle Technologies Office within the Energy Department's Office of Energy Efficiency and Renewable Energy.

Outcomes

Technology Advancement

This broad-spectrum impedance technology enables embedded, continuous monitoring of a battery's health and remaining life throughout its life cycle. The procedure takes 10 to 15 seconds to directly measure the wideband impedance spectrum during battery operation, with no significant impact on service life.[1]

Impact

The dependability of energy storage devices, mainly batteries, is becoming increasingly important to consumers, industry, and the military. As battery end-user expectations increase, and the consequences of battery failure become more pronounced, users and other stakeholders require regular updates on battery health to ensure predictable performance, personal safety, and reduction of waste.

Dynexus Technology licensed the technology and is exploring commercial applications across a range of markets, from electric vehicles (EVs) to drones, utility energy storage to telecommunications, and medical devices to military systems. The technology could help find new uses for EV batteries after their capacity fades beyond acceptable power and range performance, usually defined as below 80% of initial capacity.

The Impedance Measurement Box can effectively look at a single battery cell or battery strings commonly used in many consumer applications.
[Photo: INL]

"Monitoring battery health and remaining life will help ensure the safety and reliability of repurposed batteries, and will strengthen their viability, insurability and marketability."

David Sorum
Dynexus president and CEO

Timeline[2]

2008: Initial project funding awarded to research team (INL, University of Montana, Motloch Consulting, and Qualtech Systems)

2012: INL's Impedance Measurement Box (IMB) earns 2011 R&D 100 Award and receives additional funding from EERE to continue validation studies

2017: Under an exclusive licensing agreement, Dynexus Technology of Boulder, CO, commercializes the device for applications ranging from backup-battery-power systems to plug-in electric vehicles. Its third-generation unit can assess large-scale battery assemblies.

[1] Power Electronics. powerelectronics.com/power-management/advanced-system-measures-battery-impedance-while-use

[2] Energy.gov. energy.gov/sites/prod/files/2014/03/f10/es122_christophersen_2012_o.pdf

Integrating Thermal Energy Storage into Solid Oxide Fuel Cells

National Energy Technology Laboratory

Thicker interconnects store more thermal energy in solid oxide fuel cells (SOFCs) to enable millisecond response to increased electric loads on hybrid power systems.

Innovation

SOFCs operate at high temperatures (600–1000 ˚C) and have immense potential for thermal energy storage (TES). Thicker interconnect material—usually made of stainless steel—can double the amount of thermal energy stored and recovered without damage to the fuel cell. Initial testing found that when integrating TES, a fuel cell became more efficient, lasted longer, and was more robust. This invention eliminates the need for separate energy storage devices and can be used to overcome the problems associated with intermittent power production from renewable sources.

The work was funded by the U.S Department of Energy's Cross-cutting Research program through the Technology Development & Integration Center, Coal, in the Office of Fossil Energy.

Outcomes

Technology Advancement

Total heat capacity increases by increasing the mass of the interconnects within a fuel cell. For example, a 500 kW SOFC at baseline condition has approximately 2.6 GJ of stored thermal energy. By modifying the design and materials of construction, this amount of energy can be easily doubled, substantially improving the capacity of the SOFC as a dynamic TES device. During transient operation, heat could be stored or removed without adversely affecting the temperature gradient within the fuel cell, dramatically increasing system flexibility.

A U.S. provisional patent application has been filed on this invention, and it is available for licensing.

Impact

Steady state analyses show that increasing the mass of the interconnect material provides additional stored heat and also improves the performance of the fuel cell itself. The technology could support increased integration of intermittent renewable energy sources into power generation systems. This invention is available for licensing and/or further collaborative research.

NETL integrates hardware, pressure vessels, and real-time dynamic control models to simulate a SOFC hybrid system.
[Image: NETL]

By increasing the thermal mass of the fuel cell, less airflow would be required on the cathode for thermal management. The ohmic losses would also decrease, resulting in higher cell voltage and system efficiency.

Timeline

2017: U.S. Provisional Patent Application filed January 26, 2017

[1] OSTI.gov. osti.gov/servlets/purl/1408760

Lithium-Sulfur Materials for Safer and More Powerful Batteries

Office of Science, EERE Vehicle Technologies Office, and Oak Ridge National Laboratory in partnership with Solid Power, Inc.

Lithium-sulfur (Li-S) batteries offer the potential to reduce battery cost, increase energy density, and improve safety compared to lithium-ion batteries.

Innovation

Researchers at Oak Ridge National Laboratory (ORNL) developed innovative cathode structures, materials, and additives to improve the electronic conductivity, cyclability, and air and moisture stability of rechargeable Lithium-sulfur (Li-S) batteries. This ORNL research was funded by the U.S. Department of Energy's Office of Science and by the Vehicle Technologies Office within the Office of Energy Efficiency and Renewable Energy.

Outcomes

Technology Advancement

The ORNL research yielded six new patents or patent applications, which were later exclusively licensed to Solid Power, Inc. The company was awarded Phase 1 SBIR funding to develop a solid-state lithium-sulfide battery for large-scale energy storage and licensed a total of eight patents or patent applications related to the technology. Solid Power also entered a Strategic Partnership Project (SPP) Agreement with ORNL so that the lab's Li-S research team could assist the company in conducting materials synthesis and processing, characterization, and testing, and in producing a small amount of the material.

Impact

ORNL technology and expertise helped Solid Power develop solid-state rechargeable batteries that can provide two to three times the energy of conventional lithium ion technologies (potentially extending the range of electric vehicles by that amount).The batteries lack any volatile or flammable liquid components, eliminating many of the expensive safety features typically required for lithium-ion systems. The rechargeable battery market is expected to increase to above $20 billion by 2020. Growing application areas are in consumer electronics and electric vehicles, as well as in military, aerospace, and industrial markets.

Lithium-sulfur materials developed at ORNL could be used in BMW's electric vehicles.

"We're thrilled to add the technology developed at ORNL to Solid Power's portfolio of novel materials and processes built around manufacturing a better battery."

Douglas Campbell
President and CEO of Solid Power

Timeline

2009–2014: Combined basic and applied research at ORNL leads to six patent applications for Li-S batteries.

2015: Solid Power, Inc. is selected to receive Small Business Innovation Research (SBIR) funds (Phase 1) to incorporate the ORNL innovations into a solid-state Li-S battery for large-scale energy storage.

2016: Solid Power receives Phase 2 SBIR funding to begin production of the first large-scale battery prototypes.

2017: BMW teams with Solid Power to accelerate the commercialization of this battery technology for use in electric vehicles.[1]

[1] Tech Crunch. techcrunch.com/2017/12/18/bmw-teams-up-with-solid-power-to-develop-solid-state-batteries-for-cars/

Long-Duration Storage for the Electric Grid

Joint Center for Energy Storage Research (JCESR) in partnership with Form Energy

Sulfur-based electrochemistry of ultralow cost for weeks and months of energy storage.

Innovation

Researchers at MIT working within the JCESR developed a flow battery that uses an aqueous polysulfide negative electrode, sodium as the working ion, and an air-breathing positive electrode. These selections achieve electrical storage at exceptionally low chemical cost per unit of stored energy. JCESR's techno-economic modeling tools showed that this approach could reach system-level costs as low as that of pumped hydroelectric storage, currently the dominant form of large scale energy storage, but without its geographic limitations. This research inspired the founding of Form Energy by the MIT researchers and others in 2017 to address the growing need for large scale, long-duration electrical storage.

Outcomes

Technology Advancement

This technology can drive increased penetration of very low-cost intermittent renewables such as wind and solar. These renewables require energy storage over a wide range of time scales, skewing towards longer duration with higher penetration, in order to provide the necessary grid reliability and stability.

Form Energy, based in Sommerville, Massachusetts, counts two founders and two lead scientists amongst its JCESR alumni, and has grown to a 20 person team in just one year. Concurrently with development of its long-duration storage technology, the company has established a data analytics group that models the economics of renewable generation and grid storage in order to identify the most promising early applications.

Impact

Low-cost, long duration storage combined with renewable generation can potentially deliver dispatchable power at or below the cost of today's fossil fuel plants, if the battery can reach levelized storage costs of only a few cents per kWh. Electrochemical storage based on highly abundant, very low-cost sulfur is one of the most promising options towards this goal.

Founders of Form Energy: Yet-Ming Chiang, Mateo Jaramillo, Ted Wiley, William Woodford, and Marco Ferrara
[Photo: The Engine (MIT)]

"Breakthrough Energy Ventures chose Form Energy as one of its initial investments because the aqueous sulfur technology epitomizes innovations with great potential, developed through publicly-funded scientific research, which now require flexible, patient capital to realize its full societal impact. In this case, that impact is to provide reliable, affordable, zero-carbon electricity to the world."

Dr. David Danielson
Managing Director
Breakthrough Energy Ventures

Timeline

Aug. 2017: Baseload Renewables founded

Sept. 2017: Baseload Renewables receives funding from The Engine, MIT's fund for tough technologies[1]

Dec. 2017: Form Energy is created as a merger of Baseload Renewables and Verse Energy; receives new funding from Breakthrough Energy Ventures, Prelude Ventures, and The Engine

[1] The Engine. engine.xyz/founders/formenergy/

Nanowire Battery Technology

EERE Vehicle Technologies Office in partnership with OneD Materials

Innovation uses silicon nanowire composite materials in lithium-ion battery cells instead of pure graphite materials to provide higher energy density and better handle the volume changes common to silicon materials.

Innovation

Researchers at OneD Materials developed and demonstrated an alternative anode materials for lithium-ion batteries. This project was able to achieve the desired cycle life, energy density, and power density for the battery components. The company has also developed a scalable process for manufacturing the silicon-graphite composite.

Outcomes

Technology Advancement

Traditional anodes of lithium-ion batteries are made up of pure graphite. While it has been shown that silicon is more energy dense anode which allows for greater power density, there are issues with silicon expanding to 300% of its starting volume during battery cycling.

This project used silicon nanowires in a composite with graphite which was able to capture the advantages of silicon without the drastic cycling effects. Energy densities of 300 Wh/kg were achieved.

Impact

Adding silicon nanowires to lithium-ion anodes increases the power density and energy density of the battery. Higher power and energy density batteries have the potential to improve the performance of power tools, consumer electronics, and electric vehicles. These batteries also charge faster than traditional lithium-ion chemistries at lower temperatures. OneD's material is adaptable to individual material suppliers and manufacturers based on their needs.

Appearance of nano-wires in battery after 10 charge-discharge cycles
[DOE EERE]

"For over 10 years, Dr. Yimin Zhu and his team tested many silicon nanowire-based electrodes…and translated fundamental nanowire inventions into composite silicon/carbon materials that can be produced in large industrial quantities at a competitive cost to meet market requirements."[1]

Vincent Pluvinage
CEO, OneD

Timeline

Oct. 2011: DOE Vehicle Technologies Office (VTO) project commences; initial specifications complete

Dec. 2011: Materials properties modeled

Jan. 2014: Delivery of 2013 high energy density test cells

Sept. 2014: End of DOE VTO project

Mid-2015: OneD Materials licenses technology to EaglePicher Technologies, which builds large manufacturing plant to serve consumer electronics market[2]

[1] PR Newswire: prnewswire.com/news-releases/sinanode-silicon-nanowires-from-fundamental-research-to-industrial-production-300601502.html

[2] One D Material: onedmaterial.com/press-releases/2017/6/7/oned-material-reaches-a-new-milestone

[3] EERE Success Story: energy.gov/eere/success-stories/articles/eere-success-story-battery-company-puts-new-nanowire-technology

Notrees Wind Storage Demonstration Project

Office of Electricity in partnership with Xtreme Power, Younicos, and Duke Energy

This 24-MW battery energy storage system makes the power of the wind available on demand.

Innovation

This 24-MW energy storage project built by Duke Energy in Notrees, Texas, demonstrates the optimal dispatch of stored wind energy to accommodate the intermittent nature of the resource. This optimization improves grid stability, helps energy storage operators leverage lower grid rates, and converts variable renewable energy generation to a sustained level. [1]

Cost-shared funding was provided by the Office of Electricity and Duke Energy; Xtreme Power performed system integration.

Outcomes

Technology Advancement

The initially deployed 24-MWh lead-acid battery storage system operated successfully for five years. The control system provided the Electric Reliability Council of Texas (ERCOT) the ability to monitor system operations and confirm conformance to market protocols.

Impact

Use of the energy storage system to provide fast-responding regulation services improved the reliability of the Texas grid by minimizing deviations in the frequency of the transmission system. This project also helped inform the Texas Public Utility Commission's new regulations regarding storage and influenced similar projects nationally. [2]

By increasing the value and availability of renewable wind energy, the project may lead to more installations and improved regional energy resilience.

Wind storage demonstration system with wind turbines in the background
[Image: DOE]

"Duke Energy Renewables was a pioneer in its early installation of the Notrees Battery Park, one of the largest in the nation. Investing in updated technology will extend the life of the project, enhance performance, and expand the value it provides to the ERCOT market."[3]

Jeff Wehner
Vice President Operations,
Duke Energy Renewables

Timeline

December 2012: System went into operation

February 2013: Begins providing pilot fast-responding regulation services to ERCOT

Sept 2013: The Project received the top utility-scale energy storage innovation award at the 2013 Energy Storage North America (ESNA) Conference and Expo in San Jose, California

March 2014: Frequency regulation benefits highlighted in ERCOT report

December 2017: Upgraded 36-MW system recommissioned by Younicos with all the initial lead-acid batteries replaced by lithium-ion[4]

[1] Smartgrid.gov: smartgrid.gov/files/OE0000195_Duke_FinalRep_2015.pdf

[2] Testimony: energy.gov/sites/prod/files/2016/07/f33/5-1-15_Imre_Gyuk%20FT%20HSST.pdf

[3] Case Study: younicos.com/case-studies/notrees/

[4] News item: younicos.com/younicos-recommissions-duke-energys-36-mw-bees/

Novel Packaging Architecture for Lithium-ion Batteries

ARPA-E in partnership with Cadenza Innovation

Novel configuration of electric vehicle batteries allows double the energy density through a multifunctional pack design.

Innovation

Electric vehicles (EVs) can diversify the fuels used for transportation, increase energy efficiency, and reduce greenhouse gas emissions. To realize these benefits, EVs must compete with conventional vehicles in terms of price and driving range, both of which rely on the cost and storage capacity of the EV battery. With ARPA-E funding, Cadenza developed a new approach to EV battery manufacturing that allows for increased stored energy relative to vehicle weight.

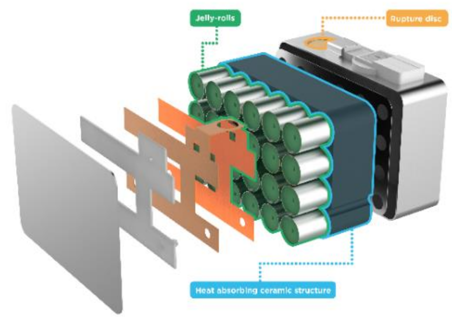
Outcomes

Technology Advancement

Cadenza’s high performance, large-format “supercell” combines 24 cylindrical-wound batteries (sometimes referred to as “jelly rolls” because of their shape) in a single container with a shared electrolyte, headspace and a singular multi-jelly roll formation cycle, greatly reducing manufacturing costs. The cell provides the energy density benefits of a small-format cylindrical-wound cell, but with several safety enhancements including improved thermal management and “pack level” fire suppression. The ceramic material surrounding the jelly-roll cells absorbs heat and discharges a gas to effectively remove heat from the supercell and prevent cascading thermal events. This packaging maximizes energy density without compromising safety.

Impact

The team met the ARPA-E battery pack goal of $125/kWh projected at scale and is now making strides towards deployment. With lower costs, driven by higher energy density and simplified safety control features (which may also enable previously “unsafe” high energy density cells), this supercell could disrupt both the EV and stationary storage markets. The novel packaging architecture opens an innovative approach to meeting the cost and performance requirements needed for the widespread adoption of EVs. Such inexpensive and safe batteries could also find application in stationary energy storage, especially for behind-the-meter storage, which can help increase penetration of intermittent renewable energy.



Cadenza Innovation Supercell
[Image: ARPA-E]

“The project team drew on the expertise of a number of partners to engineer a high-performance supercell that is competitively priced and can prevent a catastrophic thermal event in the case of overcharging, shorting, or mechanical deformation.”[1]

ARPA-E
Project Impact Sheet

Timeline

2014: Start of ARPA-E project term

2017: End of ARPA-E project term

2017: Cadenza awarded a U.S. patent for its lithium-ion battery

2018: Cadenza Innovation’s project has generated nine invention disclosures

2018: Cadenza wins a 50kW/200kWh demonstration contract with NYSERDA

[1] ARPA-E Impact Sheet: arpa-e.energy.gov/sites/default/files/Cadenza-RANGE-May1.pdf

Rapid Commercialization of High Energy Anode Materials

EERE Vehicle Technologies Office in partnership with SiNode Systems

Extending, benchmarking and demonstrating the performance of SiNode System's advanced silicon-based anode materials in battery form factors and designs relevant for electric vehicle applications.

Innovation

SiNode Systems has demonstrated a novel high energy density Si-based negative-electrode materials technology with a long-term potential to replace graphitic-based anodes in lithium-ion batteries. This project was completed by SiNode Systems, in conjunction with A123 Systems and PPG. This project was supported with funding from the DOE VTO.

Outcomes

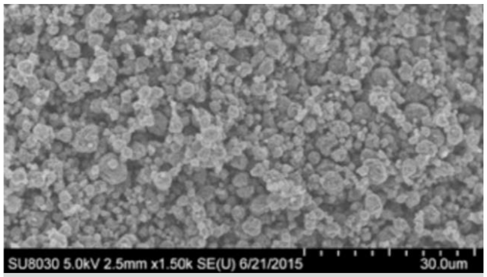
Technology Advancement

SiNode's technology uses a proprietary silicon alloy-graphene material architecture. This allows it to achieve category-leading performance and solutions to long-standing Si anode technical hurdles. The proprietary combination of silicon-based alloys and a flexible 3D graphene network helps to stabilize the active material during charge and discharge by providing an interfacial barrier between the active material and the electrolyte which can accommodate large volumetric changes through a laminar graphene sliding mechanism.

The 3D graphene-silicon architecture results in a minimization of capacity losses due to electrical disconnection, significantly improved active utilization (mAh/g) and partial stabilization of the SEI interface with a flexible physical barrier between electrolyte and active material.

Impact

SiNode Systems Si-based, negative-electrode material could enhance battery energy and power density. These advancements could reduce battery weight, improve run-times, and improve performance to meet DOE vehicle targets.



Silicon particles wrapped in a flexible, conductive graphene shell
[Photo: SiNode Systems]

"Boosting the range and reducing the weight of electric vehicles through batteries that store more energy will increase the practicality of, and consumer interest in, these cars."[3]

Kurt Olson,
PPG research fellow

Timeline[1]

2012: SiNode Systems founded based on scientific advances in Si-anode materials supported by the Office of Science EFRC.[2]

2014: DOE VTO Project Start

2015: Transition to spray-dry processing technology; Graphene structure modification results; Increase solids content and loading

2016: Design and build single-layer prototype cells; Complete pilot line design for industrial manufacturability

Nov 2017: PPG entered into a partnership with SiNode Systems to accelerate the commercialization of the technology.[3]

[1] Peer Review Presentation: energy.gov/sites/prod/files/2017/06/f35/es240_hayner_2017_p.pdf

[2] Northwestern: onlinelibrary.wiley.com/doi/abs/10.1002/aenm.201100426

[3] Green Car Congress: greencarcongress.com/2017/11/ppg-partners-with-sinode-systems-to-commercialize-high-energy-silicon-graphene-anodes.html

Regenerable Battery Electrode

Brookhaven National Laboratory

Low-cost manganese oxide cathodes for lithium-based batteries can be easily recharged *multiple times with no notable degradation of performance.*

Innovation

The high energy density of lithium-ion batteries has made them popular for use in a wide range of portable electronics, electric vehicle, and aerospace applications—but their cycle life is limited. Researchers developed a novel electrode for these batteries using an inexpensive, environmentally sustainable manganese-based material and nanowire morphology to create a long-lasting, reversible energy storage system.

This work was funded by the U.S. Department of Energy's Office of Science, Basic Energy Sciences (Center for Mesoscale Transport Properties) and Division of Materials Science and Engineering. Nanoscale measurements used resources at the Center for Functional Nanomaterials at Brookhaven National Laboratory.

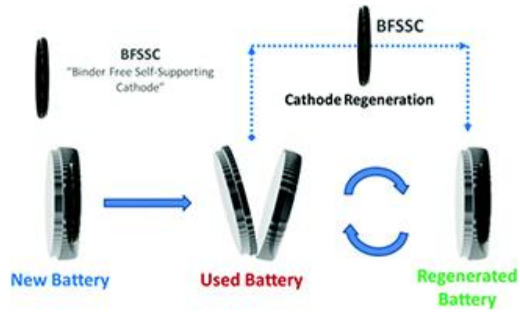
Outcomes

Technology Advancement

Researchers developed binder-free, self-supporting electrodes based on a low-cost, manganese oxide cathode material. Once depleted, the cathodes can be removed from the cell, heat treated, and reinserted in a new cell—fully restoring the delivered capacity and cycle life. The electrode structure has proven robust, showing no degradation during the cell disassembly, electrode recovery, washing, and heat treatment, eliminating the need for post processing.[1]

Impact

This electrode recycling process offers the potential to offer energy storage devices with extended electrode lifecycles. This work could lead to recycling of both anodes and cathodes by similar strategies to restore electrode performance and significantly extend battery lifetimes. Potential future applications of this invention include large battery systems for military equipment and smart energy storage for utility systems integrating renewable energy sources on the grid.



Schematic of the simple cathode regeneration process for fully restoring battery capacity and cycle life.
[Image reproduced by permission of The Royal Society of Chemistry]
pubs.rsc.org/en/content/articlelanding/2016/gc/c6gc00438e

"[This] method for recycling the cathode will lead to less battery waste and alleviate the cost of frequently replacing the battery."
Michelle A. Harris,
U.S. Department of Energy's EFRC Frontiers in Energy Research Newsletter: Summer 2016.[2]

Timeline

2014: Basic research project started in EFRC with Office of Science support

2016: PCT patent filed and paper published in *Green Chemistry* journal

[1] BNL: bnl.gov/tcp/uploads/files/BSA16-06j.pdf

[2] EFRC Newsletter: energyfrontier.us/newsletter/201607/advancing-batteries-recharge-regenerate-recycle

Regenerable Electromechanical Battery

Lawrence Livermore National Laboratory in partnership with Trinity Flywheel Batteries, General Motors, Westinghouse Electric, and Amber Kinetics

This alternative, flywheel-based battery technology promises safer and more cost-effective energy storage in utility-scale and mobile applications.

Innovation

The electromechanical battery (EMB) is a modular, flywheel-based bulk energy storage system unlike any other flywheel-based technology on the market. The EMB includes three technologies developed at the Lawrence Livermore National Laboratory (LLNL)—the electrostatic generator, passive magnetic bearings, and composite rotor—along with other innovations developed elsewhere.

Research on the three technologies was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory in partnership with Trinity Flywheel Batteries.

Outcomes

Technology Advancement

EMB systems provide 90% or greater efficiency while charging/discharging, offer a potential service life measured in decades, and are relatively inexpensive to produce and operate.

Impact

EMB is a versatile technology with many applications. As a grid-connected device, it can provide short-term frequency and voltage regulation for power quality, long-term storage of energy generated from renewable power, or customer-level energy storage at commercial and industrial facilities.

In transportation, appropriately sized EMBs (e.g., small banks of multiple devices) could power hybrid and electric vehicles, electric motorbikes and bicycles, as well as trains and commuter rail systems—which could recover energy through regenerative braking. As a lightweight and safe storage system, the EMB would be ideal in spacecraft or military applications.

The global flywheel energy storage market is projected to see compound growth at 19.6% annually through 2020.[1]

LLNL's Dick Post pioneered technologies incorporated into the EMB.
[Image: LLNL]

"We could substantially extend the range and eliminate the fire hazard posed by lithium-ion battery technology—and avoid the battery life cycle problem."

Dick Post, LLNL scientist

Timeline

1995–1996: Trinity Flywheel Batteries, General Motors, and Westinghouse Electric sponsor research at LLNL for vehicular and industrial applications[2]

2004-2011: LLNL files patents on novel electrostatic generator, bearings, and composite rotor

2013: Berkeley Energy Science Corp. licenses technology from LLNL and UC-Berkeley, then merges with Amber Kinetics

2015: Amber Kinetics uses LLNL flywheel technology in its novel Multi-Hour Energy Storage Assets to win contract with Pacific Gas & Electric as part of the Energy Nuevo project in California's Central Valley

[1] Market Intel Reports. slideshare.net/HarishPatel31/2020-competitor-analysis-market-trends-for-global-flywheel-energy-storage-market?next_slideshow=1

[2] LLNL. str.llnl.gov/str/pdfs/04_96.2.pdf

U.S. DEPARTMENT OF ENERGY | Office of TECHNOLOGY TRANSITIONS

REopt Lite Tool to Optimize PV and Battery System Sizes

National Renewable Energy Laboratory

Free online tool helps to site, size, and financially evaluate PV and battery storage projects using assumptions generated from years of experience with the more comprehensive REopt model.

Innovation

NREL has 10 years of experience with using its REopt tool to perform feasibility analyses on over 10,000 federal, military, business, campus, and community project. NREL used this experience to produce a free tool for public use called REopt Lite. The new tool is designed to provide useful information to individuals interested in financing and siting commercial PV and battery storage facilities.[1]

Outcomes

Technology Advancement

The tool utilizes a mixed integer linear program with an objective function that minimizes total lifetime cost. The constraints of the program ensure thermal and electric loads are met by a combination of selected technologies.

Future expansion of the tool will include a capability for resiliency analysis. In addition, future users will be able to access the model via an application programming interface.

To learn more about the program, a full user online manual describes the variables used in the program.[2] Entering a few simple inputs (i.e., location, annual energy consumption, building type, and utility rate) will generate an initial estimate of the sizes of PV and storage that may be cost-effective for the site, along with the potential savings.[3]

Impact

Free public access to a subset of the full REopt tool's capabilities will enable a larger audience to optimize and integrate renewable energy analyses into their decisions on renewable energy projects. The full tool has led to over 260 MW of renewable energy development, and the goal of the REopt Lite tool is to facilitate additional installations.

REopt Lite online tool webpage includes a demo and shows data entry fields.
[Image: NREL]

"REopt Lite provides access to a subset of REopt capabilities and allows a broader audience to run their own site-specific, optimized, and integrated renewable energy decision analysis in order to accelerate renewable energy and storage project development and deployment."

Kate Anderson
October 2, 2017

Timeline

2007: Initial development of the REopt tool

Sept 2016: REopt is used to catalyze renewable energy developments across the US2

Apr 2017: REopt is used to screen potential solar sites on Federal Buildings[4]

Dec. 2017: REopt Lite web tool (beta) released for free public use[5]

Mar. 2018: Planned expansion of REopt Lite tool.[6]

[1] Source: nrel.gov/news/program/2017/new-reopt-lite-tool-allows-building-owners-to-optimize-pv-system-and-battery-sizes.html

[2] User Manual. reopt.nrel.gov/tool/REopt%20Lite%20Web%20Tool%20User%20Manual.pdf

[3] NREL Fact sheet: nrel.gov/docs/fy18osti/70885.pdf

[4] Source: energy.gov/sites/prod/files/2017/04/f34/femp_reopt_fact_sheet.pdf

[5] Source: osti.gov/biblio/1415353-optimizing-storage-renewable-energy-systems-reopt

[6] Source: osti.gov/biblio/1426065-reopt-lite-web-tool-evaluates-photovoltaics-battery-storage

Silicon Anodes for Improved Capacity Electric Vehicle Batteries

ARPA-E in partnership with Sila Nanotechnologies

Advanced anodes to double the energy density of lithium-ion batteries for transportation.

Innovation

For electric vehicles, battery cost, size, and energy density will greatly influence the possibility of widespread adoption. By changing the composition of batteries to include different chemicals capable of providing higher energy density (the amount of energy relative to the size of the battery), Sila Nanotechnologies' ARPA-E project seeks to overcome these key challenges.

Sila researchers have developed a high-throughput technology for the scalable creation of new, high-capacity, nanostructured materials for electric vehicle (EV) batteries.

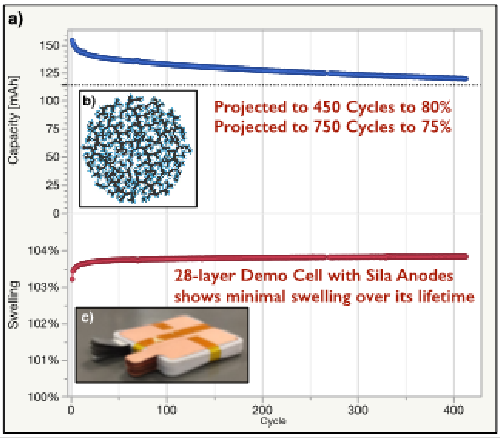
Outcomes

Technology Advancement

Sila Nanotechnologies developed drop-in, silicon-dominant anodes that increase the energy density of lithium-ion batteries without the adverse swelling effect that commonly occurs when using silicon. During the team's ARPA-E project, Sila developed new composite anode powders, which were used to manufacture thousands of small (approximately 10 mAh) single-layer pouch cells. Since then, Sila has produced 100-200 mAh multi-layer demo cells that retain high current capacity (about 80%) after as many as 400-600 cycles. To scale production, Sila built a robot assembly unit to make stacked pouch cells.

Impact

As of 2016, the team had nearly completed construction of a pilot-scale reactor to manufacture their silicon-based anode materials at a scale of kilograms per day. The company has attracted investment from corporate and financial partners and has established strategic partnerships with industry—all of which support efforts to commercialize its technology in the near future. The successful implementation of this technology will allow improvements in the energy storage capacity of today's best batteries for much less cost. Sila has raised more than $100 million from Samsung Ventures, Bessemer Venture Partners, In-Q-Tel and others. Sila also has a collaboration with BMW for potential use in its cars in the early 2020s.



(a) Sila anodes demonstrate excellent cycle life in matched full cells and less than 1%, cell level swelling over 400+ cycles

(b) Sila's technology is based on work published in 2010 in Nature Materials

(c) Sila's stacked demo cell platform uses all commercial components and build methods paired with Sila's proprietary anodes

[Image: ARPA-E]

"Sila's anodes have the potential to reduce the cell cost to less than $100/kWh, a target that would support electric vehicle goals."[1]

ARPA-E
Project Impact Sheet

Timeline

2011: Sila Nanotechnologies, Inc. founded

2012: Start of ARPA-E project term

2016: End of ARPA-E project term

2018: Sila Nanotechnologies collaborates with BMW to develop anodes for long-range EV batteries

[1] ARPA-E Impact Sheet: arpa-e.energy.gov/sites/default/files/SILA_SBIR_ExternalProjectImpactSheet_FINAL.pdf

Solana Solar Energy Project

Loan Programs Office in partnership with Abengoa Solar, Inc.

Parabolic trough concentrating solar power plant that was the first commercial project to use molten salt storage.

Innovation

In December 2010, the Department of Energy issued a loan guarantee to finance Solana, a 250-MW parabolic trough concentrating solar power (CSP) plant with an innovative thermal energy storage system. Solana represents the first deployment of this thermal energy storage technology in the United States and is one of the largest projects of its kind in the world.

Outcomes

Technology Advancement

Solana uses the first U.S. application of an innovative thermal energy storage system with molten salt as the energy storage media, combined with parabolic trough concentrating solar power (CSP) technology. While the CSP technology is similar to technology that was initially used in the 1980s, Solana is the largest energy storage project and the first in the United States to store over 1,000 MWh of energy that is dispatchable on demand without sunlight. The project spans roughly three square miles and consists of over 32,000 collector assemblies—each comprised of 28 curved mirrors—to efficiently concentrate the sun's energy into a heat transfer fluid. A synthetic oil-based heat transfer fluid heats water to produce steam, which drives a conventional steam turbine generator.

Impact

With six hours of storage, Solana can dispatch energy to customers as needed during cloudy periods and after sunset. Solana generates electricity well into the evening to help meet the summer peak demand for air conditioning in Arizona.

Rows of parabolic trough mirrors used to concentrate solar energy into a molten salt heat transfer fluid. Plant covers roughly three square miles.

[Image: Atlantica Yield & Liberty Interactive Corporation]

"Solana delivers important value to APS customers by generating power when the sun isn't shining. It also increases our solar energy portfolio by nearly 50 percent. This provides a huge boost toward our goal to make Arizona the solar capital of America."[1]

Don Brandt
President & CEO, Arizona Public Service

Timeline

December 2010: DOE closes on loan guarantee

October 2013: Solana reached commercial operation

[1] Greentech Media: greentechmedia.com/articles/read/nighttime-solar-power-arriving-in-united-states

Stafford Hill Microgrid

Office of Electricity, Sandia National Labs, Vermont Department of Public Safety, and Clean Energy States Alliance in partnership with Green Mountain Power

A @MW/3.4 MWh battery system coupled with over 2MW of solar photovoltaics (PV) located in western Vermont.

Innovation

This $10 million project is one of the first micro-grids solely powered by solar with battery backup. It is also the first known solar with storage project built on a brownfield site, a former landfill. This system typically provides solar power directly to the main power grid, but the addition of the batteries allows the system to be completely separated from the grid in the case of power outages. It is designed to provide power to the emergency shelter at Rutland High School using its combination of lithium-ion and lead acid batteries.

Outcomes

Technology Advancement

This solar and storage installation is a grid-connected microgrid which can physically be disconnected from the grid to provide power to an emergency shelter in about an hour. A direct line to the shelter allows more flexibility for the system.

Since this system is located on a landfill, special considerations were taken into account such as the landfill cap and settlement of land that could change the grade of the site. The facility's more than 7,000 solar panels were installed with ballasts to distribute their weight and the racking system includes adjustable support in case of future changes to the site.

Impact

The near-term benefits of the energy storage portion of this project are estimated to be $350,000 to $700,000 annually. The system makes money by providing instant frequency regulation, allowing the utility to arbitrage energy, flexibility in responding to energy demand, and some other benefits. The project also supports the local economy by paying lease payments over $30,000 annually.

Stafford Hill Solar and Battery system in Vermont
[Photo: U.S. Environmental Protection Agency; Courtesy of Green Mountain Power]

"Stafford Hill is a major milestone in creating more resilient and strong communities throughout Vermont. This innovative project is also a terrific example of how, working together, we can transform space that would otherwise be unusable into something that is critical to the community in times of need. This project will power the city's emergency shelter during storms, providing peace of mind to the people of Rutland."

Mary Powell
President and CEO, Green Mountain Power

Timeline[1]

2013: Green Mountain Power applied for permit to use Rutland landfill for project

Summer 2015: Project completed

Aug. 2016: System saves customers $200,000 in a single day by shaving peak demand[2]

Aug. 2018: System again saves $200,000 in a single day by shaving peak demand[3]

[1] EPA Story: epa.gov/sites/production/files/2016-07/documents/re_on_cl_rutland_case_study.pdf

[2] Green Mountain Power: greenmountainpower.com/press/gmps-solar-storage-project-becomes-first-new-england-use-solar-battery-storage-reduce-peak-demand/

[3] Green Mountain Power: greenmountainpower.com/news/gmp-beats-new-peak-delivers-bigger-customer-savings-with-growing-network-of-stored-energy/

Tehachapi Wind Energy Storage Project

Office of Electricity in partnership with Southern California Edison (SCE);

This project evaluated the use of smart inverters and utility-scale lithium-ion battery technology to address instability and capacity issues involved in incorporating highly variable generation resources on to the grid.

Innovation

Lithium-ion batteries have the ability to provide instantaneous start-up power, reducing the need for fossil fuel back-up for wind power plants. The U.S. Department of Energy worked with Southern California Edison (SCE) to install and assess a Battery Energy Storage System (BESS) connected directly to the SCE sub-transmission grid near Tehachapi, CA. The 8 MW grid-scale energy storage system uses smart inverter technologies, 604 battery racks, and over 600,000 lithium-ion battery cells (like those used in electric vehicles) to provide 8 MW of power for four hours (32 MWh).[1]

Outcomes

Technology Advancement

The BESS demonstrated the ability of lithium ion battery storage to almost instantaneous ramp up power supply to maximum capacity. Other support for the grid includes voltage stabilization, decreased transmission losses, deferred transmission investment, and frequency regulation.

Impact

As one of the biggest storage systems on a high-traffic grid, this project provides practical experience in BESS operations and reliability under real-world conditions, at scale, outside of a laboratory—and enables the manufacturer to improve and enhance the BESS hardware and software for future projects.

The project helped to define and refine the process for interconnecting batteries to the utility grid, integrate them into the power market, and provide financial data to help value other proposed battery systems. It expands the amount of renewable wind energy available on the grid while improving power quality and system reliability.

Energy Storage equipment for wind storage project
[Photo: NETL/SmartGrid.gov]

"Grid-scale energy storage…will contribute to optimizing grid performance and integrating more renewable energy resources. This demonstration project will give us a significant amount of insight into the operational capabilities of large-scale, lithium-ion battery storage."[2]

Doug Kim
Director of Advanced Technology, SCE

Timeline

June 2011: Completed installation of baselining equipment

Feb. 2012: Began facility construction

Sept. 2013: Deployment of Energy Storage System

June 2014: Start of Measurement and Verification Testing

June 2016: Completion of Measurement and Verification testing [3]

[1] DOE Fact Sheet. smartgrid.gov/files/OE0000201_SCE_FactSheet.pdf

[2] Edison. newsroom.edison.com/releases/sce-unveils-largest-battery-energy-storage-project-in-north-america

[3] Technology Performance Report. osti.gov/servlets/purl/1349233

Turning Large Commercial Buildings into Batteries

EERE Office of Building Technologies in partnership with QCoefficient, Inc.

Predictive control algorithm exploits the mass of large commercial buildings for thermal energy storage.

Innovation

Employing passive and/or active strategies for thermal energy storage (TES) can shift all or a portion of a building's structural and equipment cooling needs to hours when electricity prices are lower. Researchers used this principle to develop a system that utilizes large commercial building mass as a thermal energy storage (TES) medium to optimize building load profiles and reduce costs. This research was supported by the U.S. Department of Energy's Building Technologies Office (BTO)

Outcomes

Technology Advancement

The system uses a multi-objective optimization and predictive control algorithm that analyzes a building's composition and cooling demand profile, then reschedules peak uses for non-peak periods to get lower utility rates. The algorithm uses information about the building's existing HVAC efficiency characteristics under load, as well as short-term weather forecasts, electricity price data, and the building's energy profile (its size, structural materials, envelope characteristics, and occupancy) to devise an optimal TES/HVAC control strategy.

The algorithm provides an operating strategy that does not compromise occupant comfort but takes advantage of the energy embedded in the physical structure of the building—from its foundation to its furniture—to dynamically reshape the building's cooling load profile.

Impact

Heating, ventilation, and air conditioning (HVAC) systems account for 48% of all energy used in U.S. buildings, primarily during the summer. The predictive control algorithm successfully reduces site energy costs by 20-40%. During a summer 2012 demonstration in Chicago, QCo displaced 1,500 megawatt hours of peak energy while increasing off-peak use by 600 MWh, saving one building (Willis Tower) $250,000.

Large commercial buildings hold significant embedded energy that can be used to cut demand during high-cost peak periods.

"Hot weekdays present a great economic opportunity for thermal energy storage, especially in grid-congested cities."
Sandro Plamp[1]
QCoefficient Director of Engineering

Timeline

2008: Researchers at QCo and University of Colorado use BTO assistance to begin developing building energy management algorithms to harness drywall and concrete as thermal energy storage

2012: QCo commercializes system and demonstrates it in large commercial buildings in downtown Chicago, Houston, and Washington D.C.

2013: Field demonstration results highlighted in article[2]

2015: QCo publishes case study, demonstrating peak demand reductions[3]

2017: QCo continues to market and enhance its software to integrate HVAC with grid markets and operations

[1] Source: energy.gov/eere/buildings/articles/qcoefficient-uses-energyplus-reduce-willis-tower-energy-bills

[2] Source: qcoefficient.com/news-articles/skyscrapers-that-act-like-batteries-this-entrepreneur-says-yes

[3] Source: qcoefficient.com/assets/documents/QCo1506pve.pdf

Utility Scale Battery Energy Storage

Office of Electricity, Massachusetts Department of Energy Resources, Sandia National Labs, and Clean Energy States Alliance in partnership with Sterling Municipal Light Department

2 MW, 3.9 MWh grid energy storage solution in Sterling, Massachusetts. This project is a battery energy storage system (BESS) working in conjunction with two nearby solar plants.

Innovation

This installation is a first of its kind in Massachusetts. It provides resiliency and cost savings for the Sterling municipality in addition to letting the municipality isolate from the main grid during a power outage and provide up to 12 days of power to emergency services. The battery system consists of lithium-ion batteries from NEC Energy Solutions that were funded by a grant from the Massachusetts Department of Energy Resources with additional financing form the Office of Electricity.

Outcomes

Technology Advancement

This battery storage system was first put into use in December 2016, only three months after the project's groundbreaking. The estimated payback period of the project is 7 years (does not include project grants) which is funded by cost savings for ratepayers and the utility in addition to providing ancillary services and allowing for energy arbitrage.

The benefits quickly demonstrated by this project has provided many data points to encourage installation of similar systems in other small municipalities. As of April 2017, this project provided the highest watts per customer for any utility energy storage project in the world.[1]

Impact

The battery energy storage system was able to reduce demand charges by $17,000 in just 33 working days.[2] The project will continue to make money through capacity reductions, transmission reductions, arbitrage, and frequency regulation. Sterling municipality also gets around 35% of its power from renewable sources, so the battery system is also useful for renewable integration.[3]

Workers install battery energy storage system in Sterling, MA.
[Photo: Sterling Municipal Light Dept.]

"The lessons learned from this project will be valuable in determining the economics of energy storage in various applications, in addition to helping understand the system metrics that are most important in determining system reliability and safety."

Dan Borneo
Principal/Program Lead
Sandia National Lab

Timeline[1,4]

Oct. 2016: Groundbreaking on project

Dec. 2016: Battery system operational

2017: Sterling municipality received Greentech Media 2017 Grid Edge Award

April 2018: Completion of the community solar and energy storage project in Sterling, MA

[1] CSEA Slides. cesa.org/assets/2017-Files/ESTAP-webinar-slides-4.27.2017.pdf

[2] SMLD Website. energysterling.com/batterystorage.asp

[3] Greentech Media. greentechmedia.com/ articles/read/the-2017-grid-edge-awards#gs.9lXpHsw

[4] Business Wire. businesswire.com/news/ home/20180417006722/en/Community-Solar-Storage-Project-Massachusetts-Dedicated-Today

Valuing Advanced Pumped Storage Hydropower

Argonne National Laboratory, the National Renewable Energy Laboratory, and the DOE Water Power Technologies Office in partnership with Siemens PTI, MWH, and Energy Exemplar

Advanced computer simulation models were created to determine the value that Pumped Storage Hydro (PSH) brings to the grid, especially when variable solar and wind resources are also interconnected.

Innovation

This project created dynamic models for advanced PSH technologies, showing the way that PSH systems interact with the rest of the grid. Prior to this study, dynamic models for key technologies were not available in the US. The creation of these models quantified the economic benefit of using advanced PSH technologies for the first time. Understanding the true value of these projects can help spur future development of new systems.

The project lead was Argonne National Laboratory and key core team members included Siemens PTI, MWH, Energy Exemplar, and the National Renewable Energy Laboratory (NREL). The funding support for the study was provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

Outcomes

Technology Advancement

An advanced technology modeling task force group was developed to investigate state-of-the-art computer models representing the behavior and operation of PSH plants. The task force group identified two important PSH technology advancements that had not been fully characterized in prior modeling efforts: adjustable speed PSH plants and ternary pumped storage units.

Impact

Using the simulations, researchers analyzed production costs and revenues for advanced PSH systems and determined the benefits and value they bring in both regulated and competitive electricity market environments. The simulations showed that PSH can provide production cost savings, satisfy reserve requirements, and aid renewable integration.

Seneca pumped storage reservoir in Warren County, PA
[Photo: U.S. Army Corps of Engineers]

PSH plants provide a variety of benefits to the power system. In the past the benefits of PSH plants were usually associated only with the energy arbitrage and contingency reserves, but this study clearly shows these are just a fraction of the total value PSH plants provide to the system.[1]

Timeline

April 2012: Project commissioned

Aug. 2013: Review of existing PSH simulation models completed.

Aug. 2013: Initial modeling completed for advanced PSH systems

Oct. 2013: Adjustable speed PSH production cost evaluation completed

Nov. 2013: Study completed analyzing the use of PSH for frequency control

June 2014: Final analysis completed, quantified value of grid services from PSH[2,3]

[1] Article: hydroworld.com/articles/hr/print/volume-33/issue-7/articles/how-advanced-pumped-storage-technologies-contribute-to-the-system.html

[2] ANL Article: ceeesa.es.anl.gov/projects/psh/psh.html

[3] EERE: energy.gov/eere/water/downloads/pumped-storage-hydropower-detailed-analysis-demonstrate-value-modeling-and

Zinc-Bromide Flow Batteries

Office of Electricity, ARPA-E, and National Renewable Energy Laboratory in Partnership with Primus Power

A zinc-based, rechargeable flow battery is now at production level after Office of Electricity funding.

Innovation

Office of Electricity provided Primus Power support to deploy a 25 MW/75 MWh zinc-based flow battery through $14 million in ARRA funding. This project changed over time and contributed to Primus Power's development of the EnergyPod 2, a 25 kW/125 kWh modular zinc-bromide flow battery. ARPA-E also played an initial role by providing $2 million to support the development of novel electrodes in the flow battery. NREL used the battery in an advanced microgrid system demonstration with solar photovoltaic (PV) energy to provide secure, reliable power for the Marine Corps Air Station Miramar and a host of services to support the central grid. This large military microgrid project at the San Diego naval base received $20 million from Congress.[1]

Outcomes

Technology Advancement

The second-generation zinc-bromide battery offers increased battery resiliency and conductivity, and its energy capacity does not degrade over time. It has a rated capacity of 25 kW and can operate for five hours, providing 125 kWh.

The system can operate at 70% round trip efficiency and achieves a 100% depth of discharge. It can also operate in a wide range of temperatures (-30°C to 50°C). In addition, it has fewer maintenance costs because it has no membrane and only a single set of pipes and pumps.[2]

Impact

More efficient and cost-competitive flow batteries can be grouped into pods that store energy for later use or integration on the grid as needed, improving grid resiliency. Continued development of zinc-bromide flow batteries will further drive down costs for utilities, renewable energy developers, businesses, and campuses. Given the long service life of these flow batteries, at higher production volumes, they could present a cost competitive alternative to lithium-ion batteries.

Early version of EnergyPod installed at MCAS Miramar.

[Photos: Primus Power]

"The EnergyPod represents a breakthrough in energy storage technology due to its long life—20 years, long duration, and fade-free performance (no loss of capacity for the life of the battery)."[2]

Paul Ferrera
Business Development, Primus Power

Timeline[3]

2010: Cooperative agreement using ARRA funds started

2010-2012: ARPA-E project term[4]

2013: Beta testing

2015: First production EnergyPods built

2015: Primus Power EnergyPod commissioned at Marine Corps Air Station (MCAS) Miramar.

2016: More than 20 zinc-bromide flow battery systems delivered[4]

[1] Microgrid Knowledge. microgridknowledge.com/military-microgrid-projects/

[2] Batteries International: batteriesinternational.com/primus-power-launches-second-generation-zinc-bromine-flow-battery/

[3] NETL Cooperative Agreement: osti.gov/servlets/purl/1346202

[4] ARPA-E Impact Sheet: arpa-e.energy.gov/sites/default/files/Primus_GRIDS_ExternalProjectImpactSheet_FINAL.pdf

Office of Technology Transitions
U.S. Department of Energy

The Office of Technology Transitions develops DOE's policy and vision for expanding the commercial impacts of its research investments and streamlines information and access to DOE's National Labs, sites, and facilities to foster partnerships that will move innovations from the labs into the marketplace.

U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

August 2018

U.S. DEPARTMENT OF ENERGY | Office of TECHNOLOGY TRANSITIONS

energy.gov/technologytransitions