



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.

Timeline

- **April 2015:** Proof of concept paper published
- **October 2015:** ARPA-E IDEAS grant awarded to further explore acoustic method
- **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
- **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

Loan Programs Office in partnership with Nissan North America

Scaling up domestic advanced battery manufacturing for electric vehicles

Timeline

- **2010:** DOE closes on Nissan loan
- **2012:** Advanced battery production starts
- **2017:** Nissan repays loan in full



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.

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
- **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

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.

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



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.

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

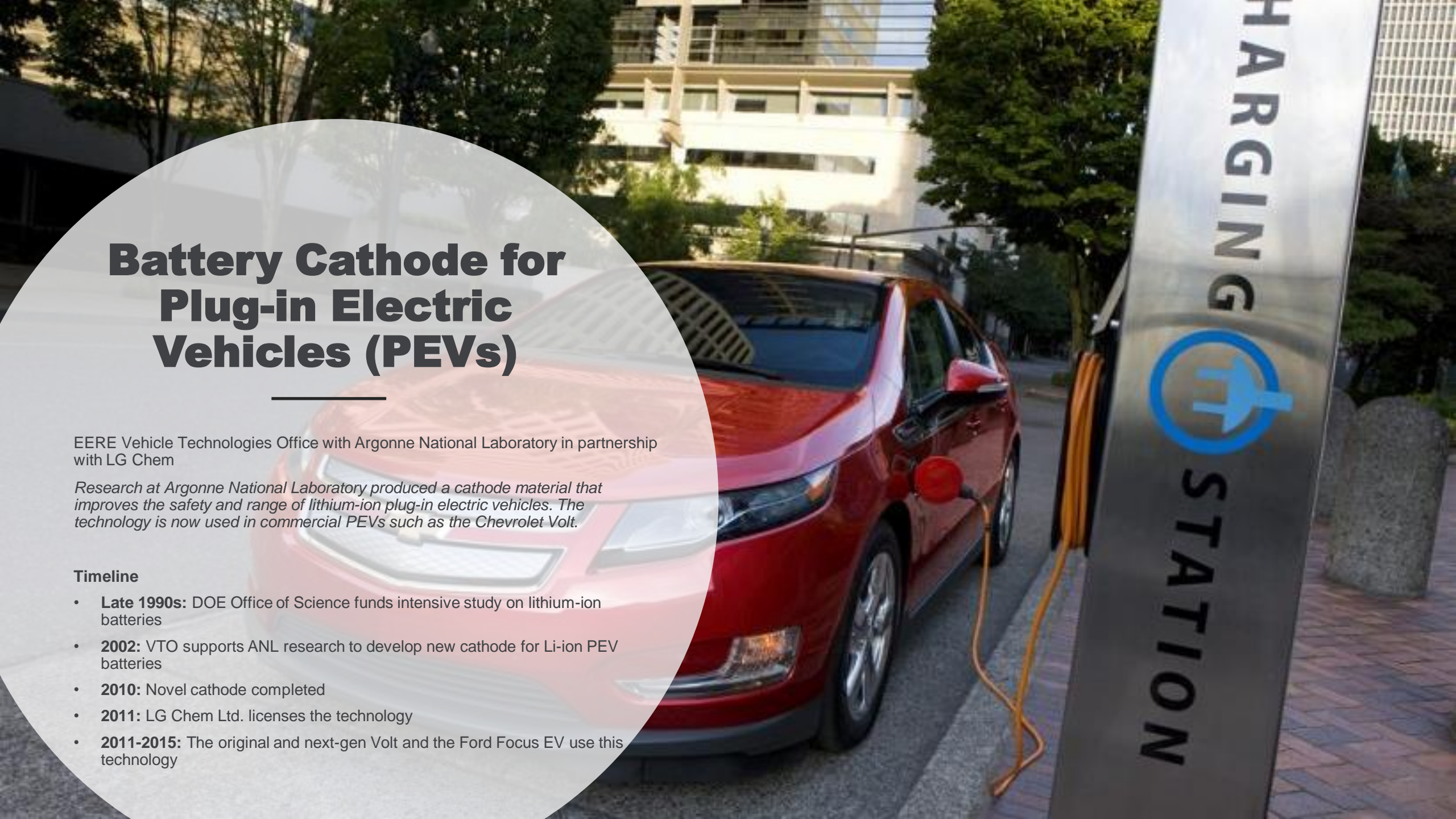
Battery Cathode for Plug-in Electric Vehicles (PEVs)

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.

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



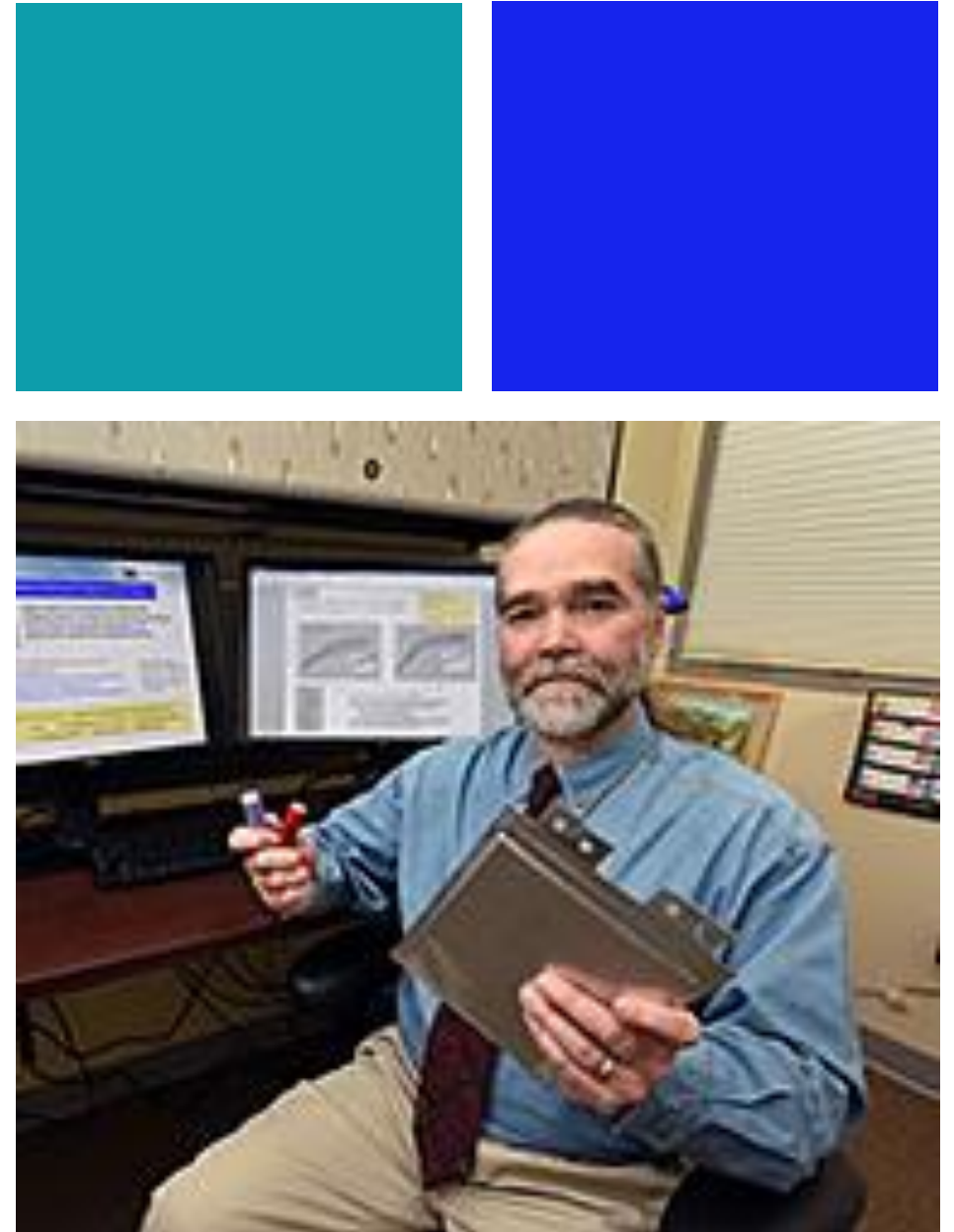
Battery Diagnostic Software

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.

Timeline

- **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





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.

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
- **2014:** Microgrid helps avoid small outages
- **2015:** CEC grant enables interconnect with nearby 26-MW solar facility

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.

Timeline

- **2010:** Project starts
- **2012:** Project completed
- **2013:** Receives 2013 R&D 100 Award
- **2014-2016:** LBNL develops second and third



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

Timeline

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





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.

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.



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.

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/sCO₂ heat exchanger and novel particle curtain designs
- 2018: New DOE award extends R&D on high- temperature components, integrated assemblies, and systems testing

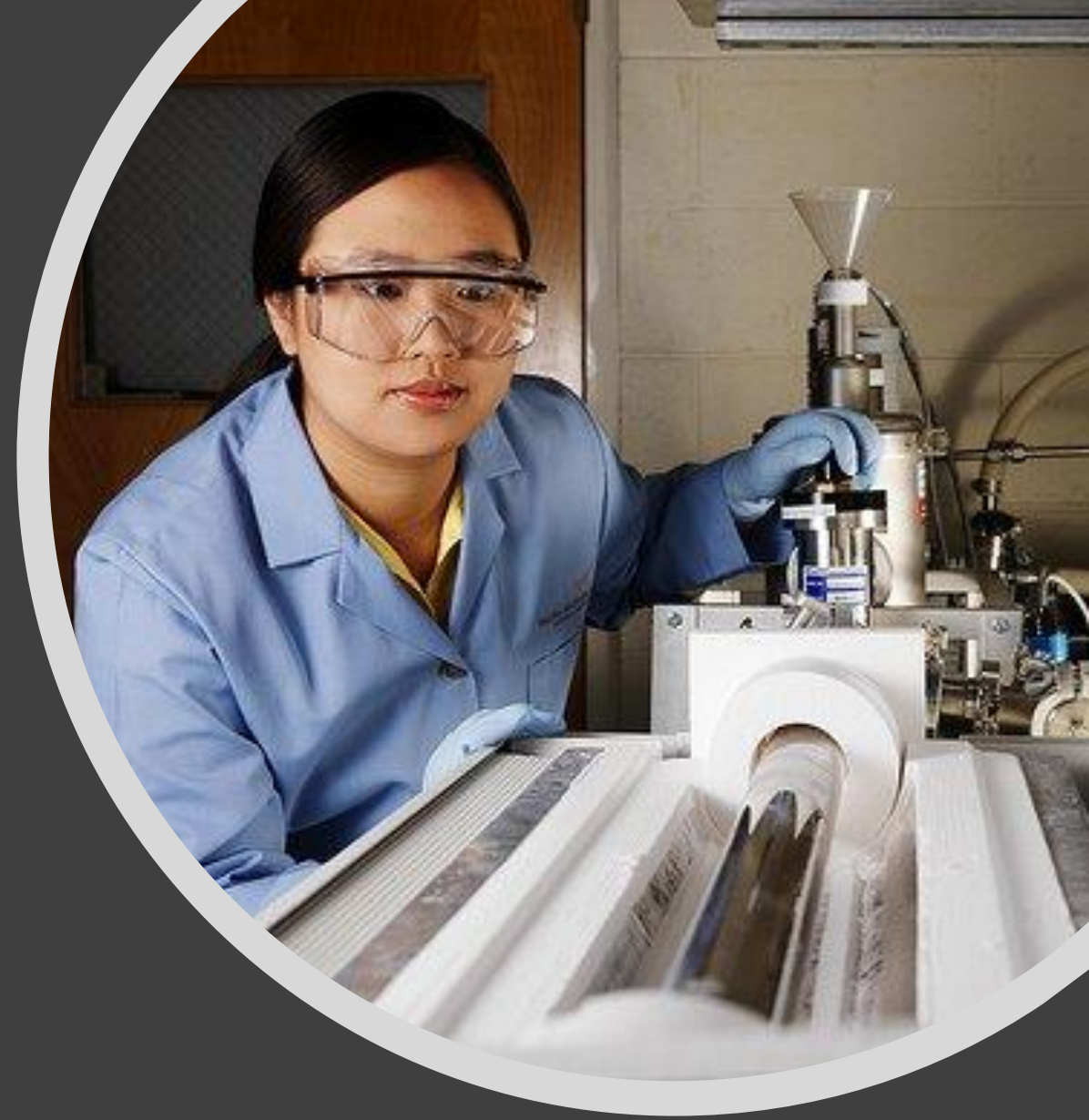
Graphene Material to Reduce Battery Charge Time

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.

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.



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.

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
- **2015:** Project contributes to improvements in operations, storage devices, system controls, and balance of plant
- **2018:** Beacon acquired by RGA Investments; Beacon maintains plants in Stephentown, NY and Hazle, PA

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

Timeline

- **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.



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

Timeline

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



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.

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.

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.

Timeline

- Aug. 2017: Baseload Renewables founded
- Sept. 2017: Baseload Renewables receives funding from The Engine, MIT's fund for tough technologies
- 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



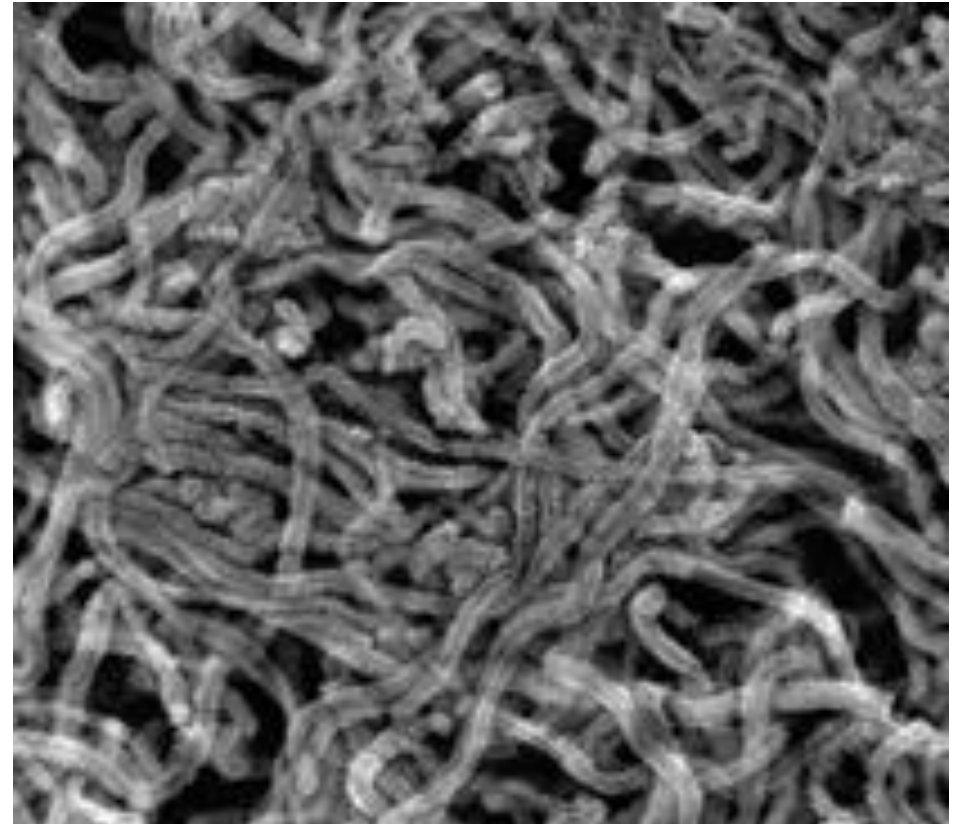
Nanowire Battery Technology

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

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





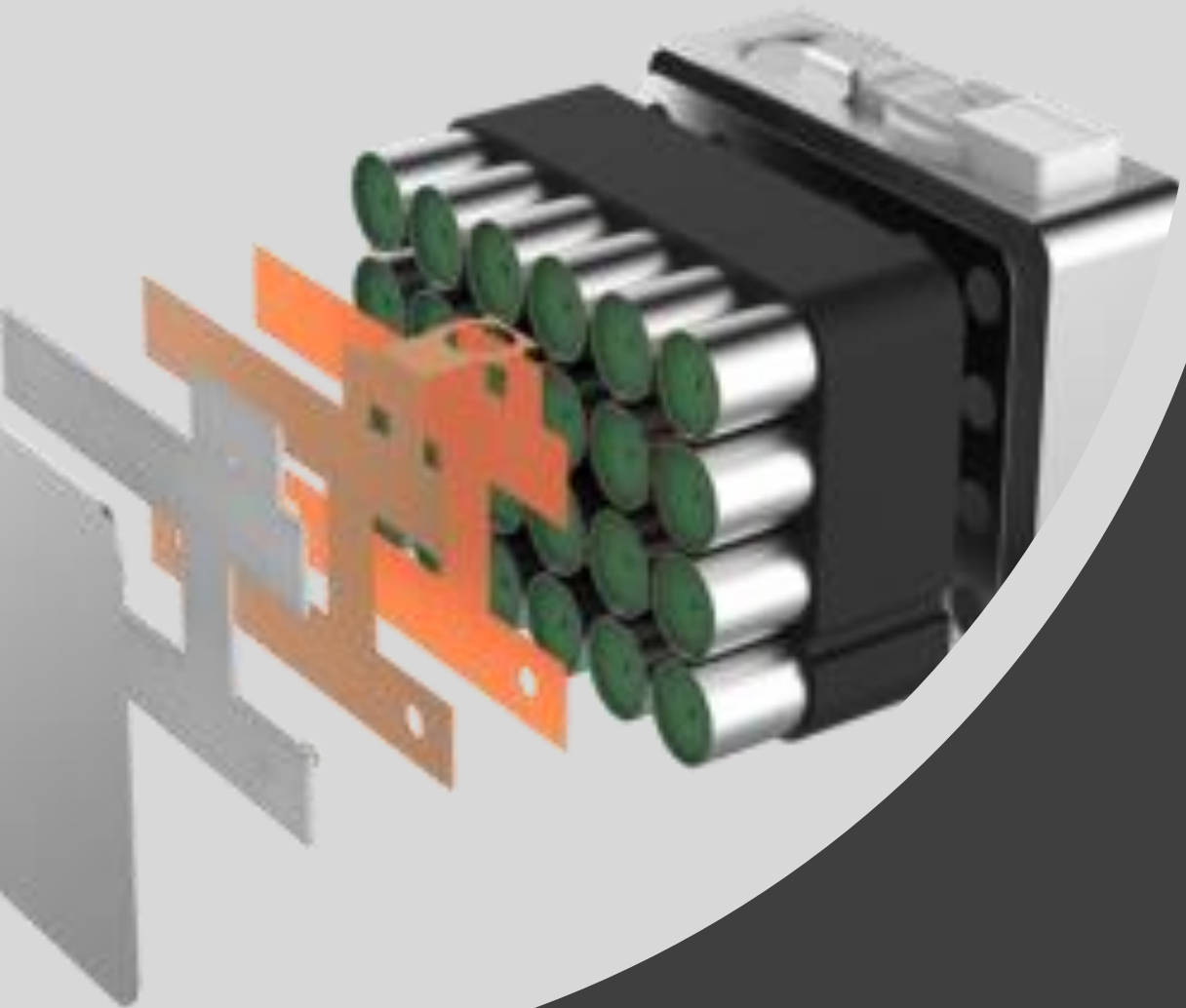
Notrees Wind Storage Demonstration Project

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.

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



Novel Packaging Architecture for Lithium-ion Batteries

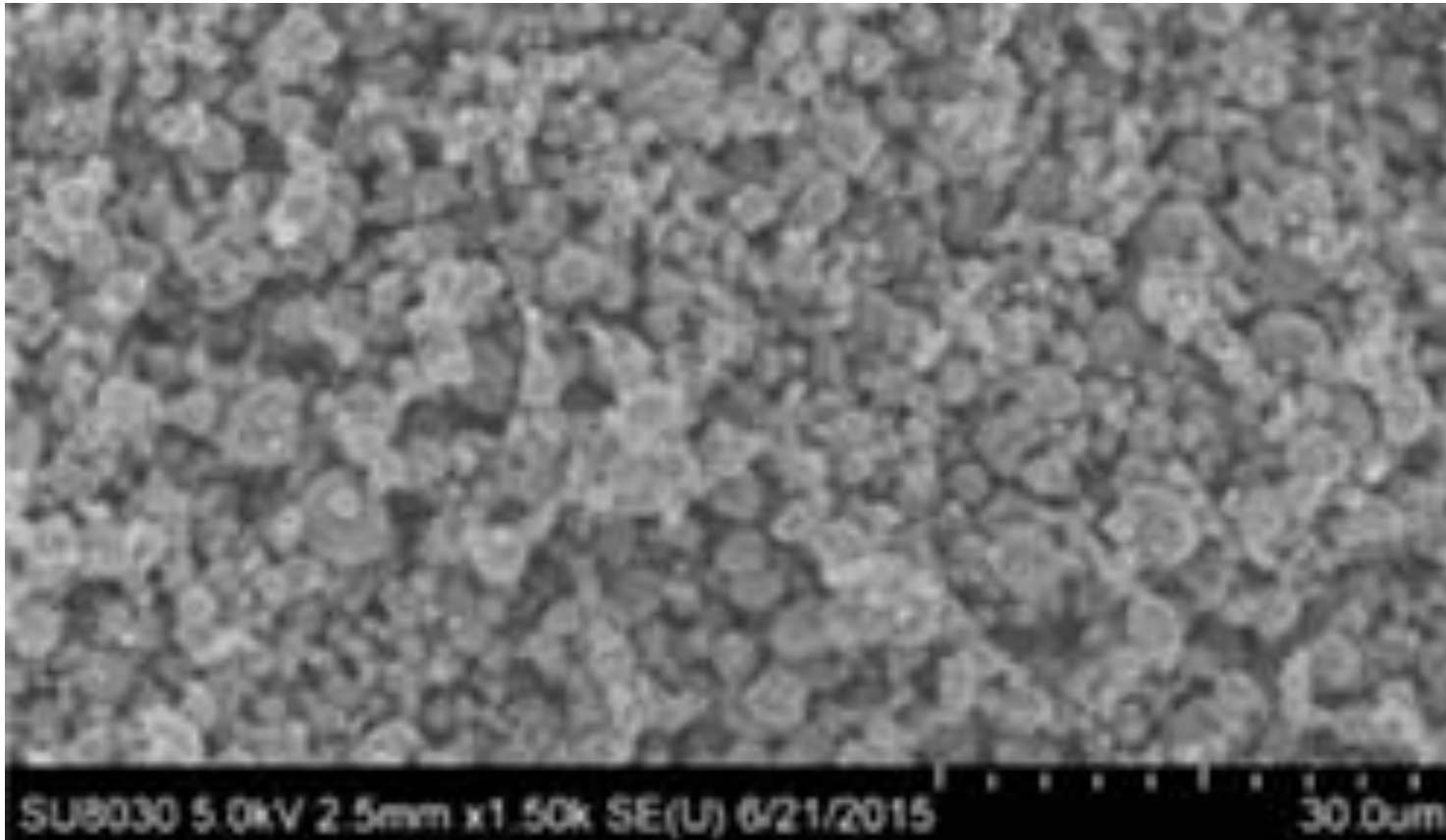
ARPA-E in partnership with Cadenza Innovation

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

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

Rapid Commercialization of High Energy Anode Materials

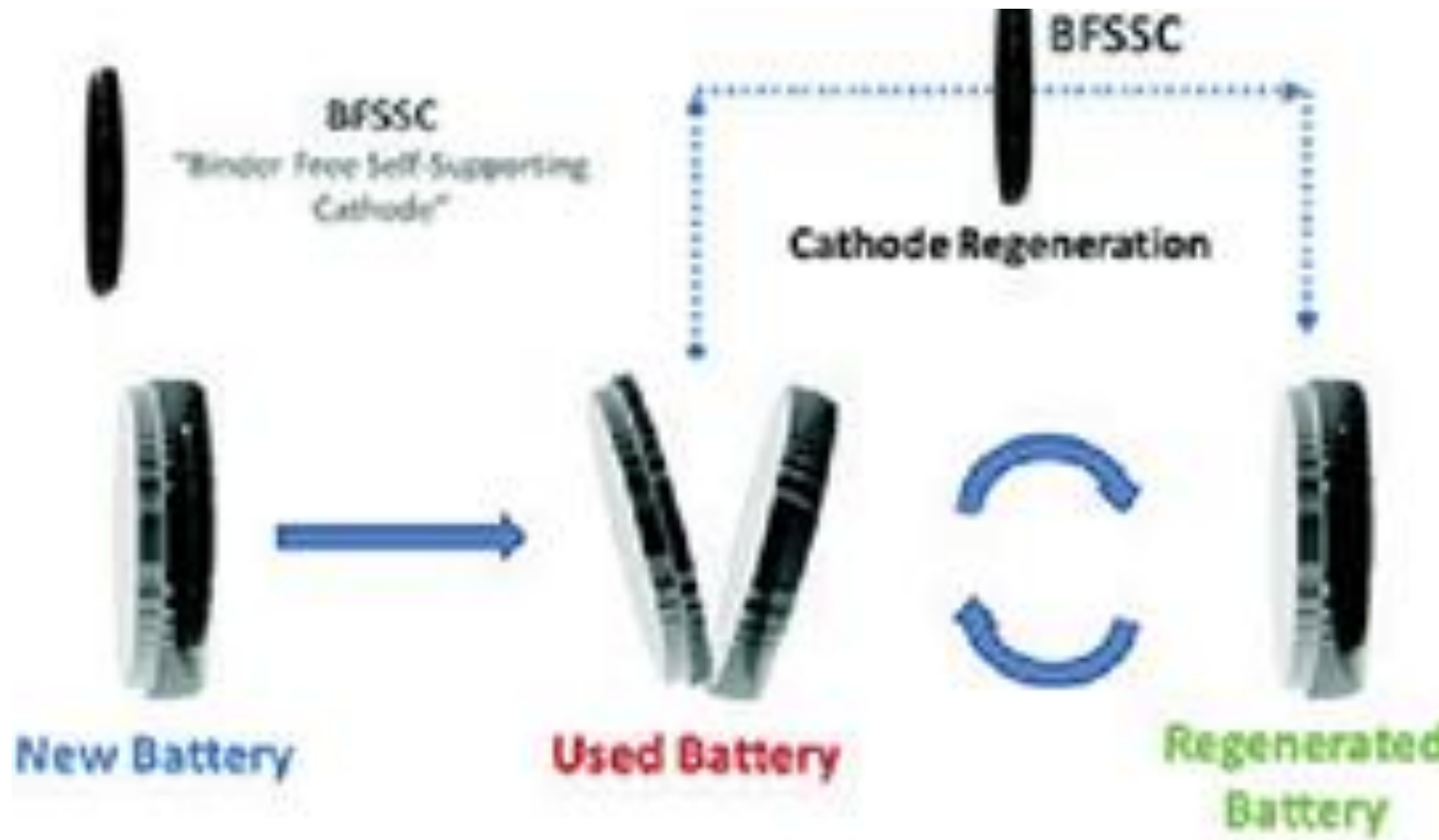


EERE Vehicle Technologies Office in partnership with SiNode Systems

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.

Timeline

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



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.

Timeline

- 2014: Basic research project started in EFRC with Office of Science support
- 2016: PCT patent filed and paper published in Green Chemistry journal

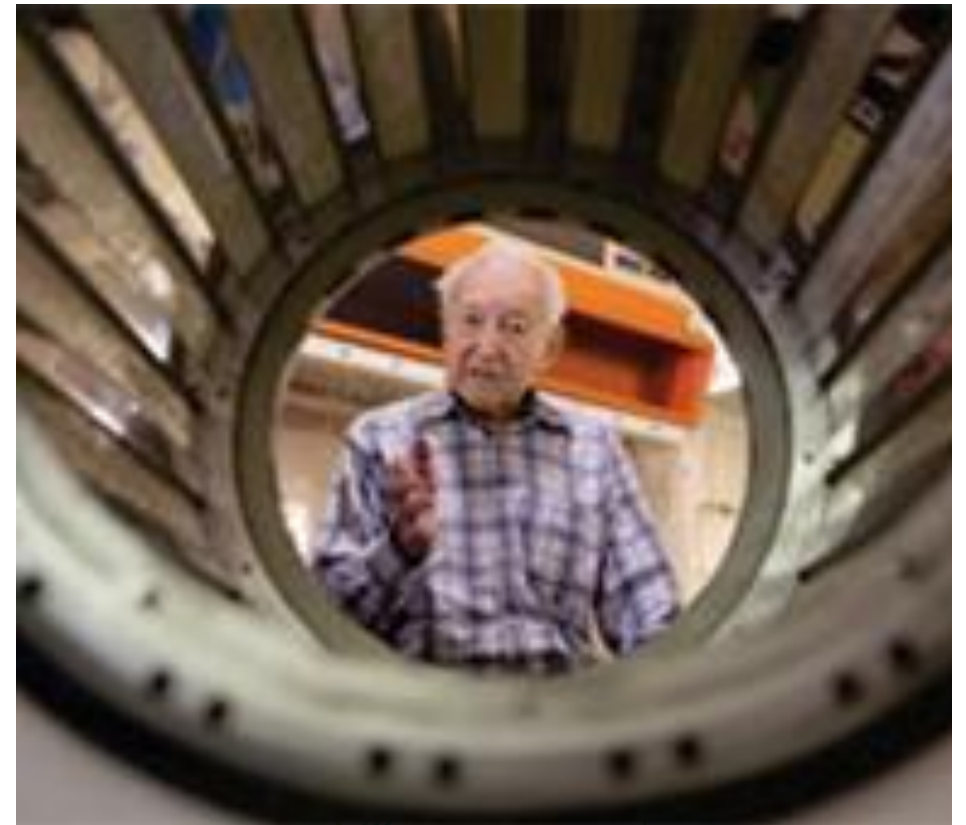
Regenerable Electromechanical Battery

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.

Timeline

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



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.

Timeline

- 2007: Initial development of the REopt tool
- Sept 2016: REopt is used to catalyze renewable energy developments across the US
- Apr 2017: REopt is used to screen potential solar sites on Federal Buildings
- Dec. 2017: REopt Lite web tool (beta) released for free public use
- Mar. 2018: Planned expansion of REopt Lite tool.

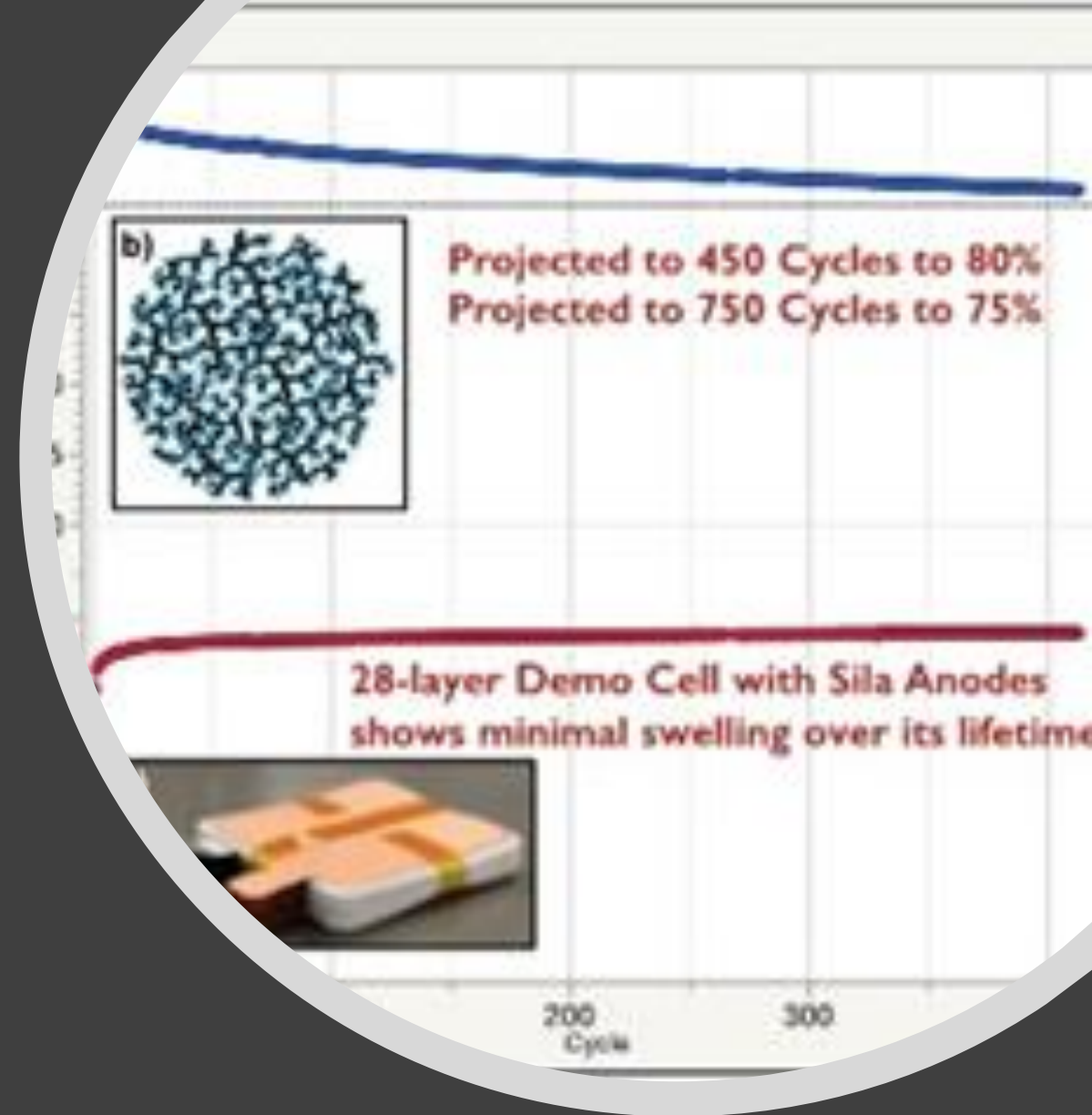
Silicon Anodes for Improved Capacity Electric Vehicle Batteries

ARPA-E in partnership with Sila Nanotechnologies

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

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





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.

Timeline

- December 2010: DOE closes on loan guarantee
- October 2013: Solana reached commercial operation



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.

Timeline

- 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
- Aug. 2018: System again saves \$200,000 in a single day by shaving peak demand

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.

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



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.

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
- 2015: QCo publishes case study, demonstrating peak demand reductions
- 2017: QCo continues to market and enhance its software to integrate HVAC with grid markets and operations





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.

Timeline

- 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



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.

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}

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.

Timeline

- 2010: Cooperative agreement using ARRA funds started
- 2010-2012: ARPA-E project term4
- 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

