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## **DOE Electrification Systems R&D Overview for Fiscal Years 2016-2017**

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### **Summary**

This paper provides an overview of the fiscal year (FY) 2016–2017 Electrification Systems R&D projects funded by the Vehicles Technologies Office (VTO) of the U.S. Department of Energy (DOE). VTO follows a comprehensive research plan covering electric drive technologies (EDT), advanced batteries, grid integration, and extreme fast-charging (XFC). VTO leverages significant R&D resources by teaming with the automotive industry, suppliers, developers, national laboratories, and universities to address technical challenges for electric drive vehicles. The paper discusses key recent highlights for the Electrification Systems R&D in general (with special emphasis on electric drive technologies R&D) and its linkage with research on energy efficient mobility systems (EEMS).

*Keywords: electric drive, battery, charging, BEV, federal government*

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### **1 Introduction**

This paper provides an overview of the fiscal year (FY) 2016–2017 electrification systems R&D projects funded by the Vehicles Technologies Office (VTO) of the U.S. Department of Energy (DOE). The organizational structure of the office is shown in Figure 1. VTO collaborates with industry leaders through

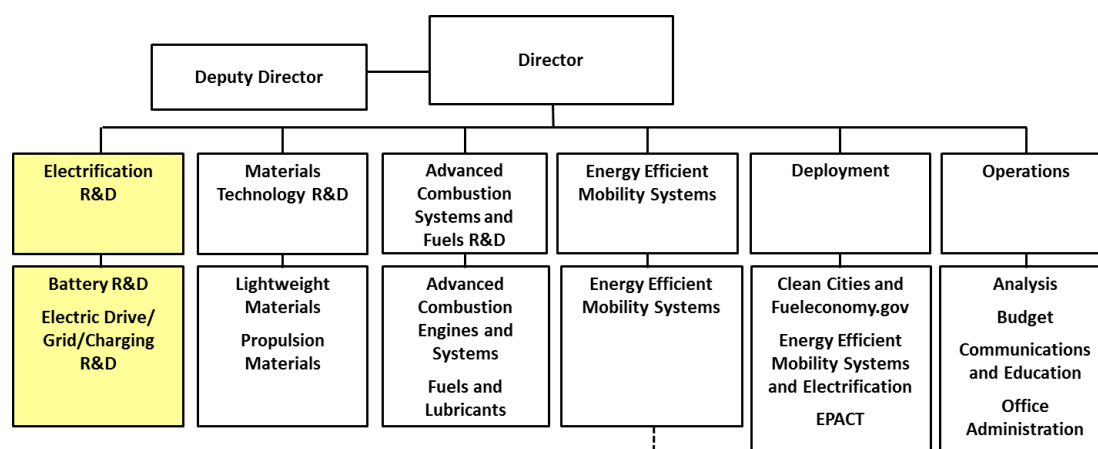


Figure 1: Organization chart for the DOE Vehicle Technologies Office (VTO).

partnerships (e.g. U.S. DRIVE [1]) to accelerate the development of advanced technologies, including highly efficient combustion engines and fuels, lightweight materials, and advanced batteries and electric drive systems. Electrification systems R&D includes research on electric drive technologies, advanced batteries, grid integration, and extreme fast charging (XFC). VTO-funded R&D projects on transportation technologies are conducted in collaboration with industry stakeholders. Status updates on Electrification Systems projects have been provided at prior EVS meetings [2]. The electrification systems R&D FY 2017 budget was approximately \$146 million (see Table 1). It includes electric drive/grid/charging infrastructure R&D and battery R&D, as described below.

Table 1: Recent Electrification Systems R&D Budgets

Fiscal Year (FY)	2011	2012	2013	2014	2015	2016	2017
Budget (\$, Million)	\$145.8	\$164.9	\$153.4	\$151.3	\$140.1	\$173	\$146

## 2 Electric Drive/Grid/Charging Infrastructure R&D

### 2.1 Electric Drive Technologies R&D

The target for electric drive technologies (EDT) R&D is a 100 kW electric drive system costing no more than \$6/kW, to be developed by 2025 (representing a 50% reduction in cost from the 2015 baseline). VTO EDT research [3] provides support and guidance toward that target. It is focused on developing new power electronics, electric motor, and traction drive system technologies that leapfrog current technologies, leading to electric drive systems with lower cost and improved efficiency. Areas of development include novel traction motor designs for increased power density and lower cost, inverter technologies incorporating advanced wide bandgap (WBG) semiconductor devices to achieve higher efficiency and higher reliability in higher-temperature environments, converter concepts integrating offering reduced size, weight, and cost, new on-board battery charging electronics for decreased cost and size, more compact and higher-performing thermal controls achieved through novel thermal materials and innovative packaging technologies, and integrated motor-inverter traction drive system architectures that optimize the technical strengths of the underlying PE and electric machine subsystems. The following sections describe some recent EDT project highlights.

#### 2.1.1 High Power Density Ferrite PM Motor

Most HEV and EV motors use permanent magnets (PMs) with heavy rare earth (HRE) materials such as neodymium and dysprosium because they facilitate high power density, specific power, and efficiency. Due to significant market volatility associated with HRE materials, viable alternatives to HRE-based machines are needed to enable mass production. Oak Ridge National Laboratory (ORNL) researched and designed a non-HRE-based alternative motor design, specifically a high power density ferrite PM motor and implemented a novel Guided Random Search method to optimize the ferrite PM motor design. After extensive optimization, the simulated peak power of the motor was 60 kW at 2,800 RPM, over 90 kW at about 4,500 RPM, and greater than 55 kW at 14,000 RPM. Figure 2 provides an efficiency map for the motor design. ORNL estimates that the per-unit manufacturing cost at 100K units is projected to be less than \$450 exceeding DOE 2020 targets.

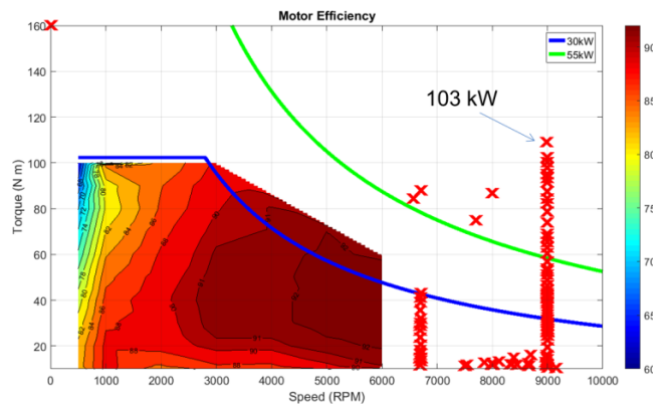


Figure 2: Performance and efficiency data from dynamometer testing of ORNL’s ferrite PM prototype motor.

### 2.1.2 Thermal Management of WBG Technology for Power-Dense and High-Temperature Systems

Capacitors are critical power electronics components and their low maximum operating temperatures (85°C) pose thermal management challenges in high-temperature WBG environments. Using high-performance computing resources, the National Renewable Energy Laboratory (NREL) quantified three-dimensional steady-state and transient temperatures (and heat flows) at component and system levels for an automotive inverter operating at higher junction temperature enabled by WBG devices (from 175°C to 250°C) (Figure 3). It evaluated the efficacy of capacitor thermal management approaches and demonstrated that cooling the electrical interconnections was a more effective thermal management strategy than directly cooling the capacitors – enabling capacitors to operate within allowable temperature limits at WBG junction temperatures up to 250°C.

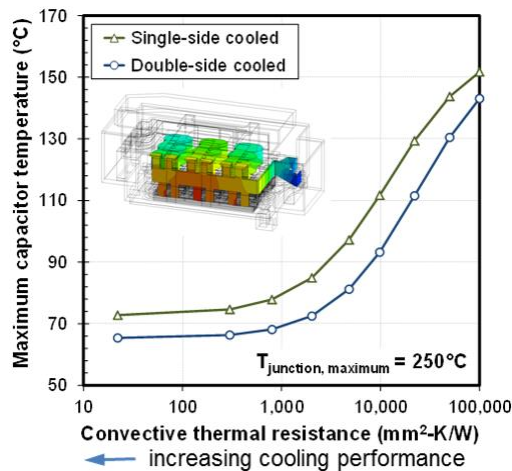


Figure 3: Simulation-predicted capacitor temperatures for a WBG operating condition with results showing that electrical interconnection cooling enables capacitor temperatures <85°C for WBG device temperatures up to 250°C.

### 2.1.3 High Temperature DC Bus Capacitor Cost Reduction & Performance Improvements

Sigma Technologies, and project partners Delphi Automotive and Oak Ridge National Laboratory made significant progress in developing improved DC bus capacitors, fabricating and packaging these capacitors, and developing a production business plan. Full size (300µF, 500µF and 700µF) capacitors have been produced which meet or exceed technical targets for DC bus capacitor performance and packaged life testing shows stability under various environmental conditions, including high temperature automotive environments (see Table 2).

Table 2: Sigma PML capacitor performance compared to DOE capacitor development targets for a ~700  $\mu\text{F}$  capacitor

Characteristic	DOE Target	PML Capacitor
Temperature	-40 to 140°C	-40 to 140°C
Loss	1%	<1%
Volume	<0.6L	<0.3L
Cost	< \$30	< \$20

This Sigma-developed capacitor uses a solid-state Polymer-Multi-Layer (PML) construction comprising radiation-cured polymer dielectrics and aluminum electrodes, forming a large area Nano laminate that can be segmented into individual capacitors. Sigma is now designing and fabricating a production scale machine.

### 2.1.4 Application of SiC Power Devices in Hybrid Electric Vehicle Drive Systems

In a VTO cost-shared project, Cree/Wolfspeed demonstrated the application of 900V Silicon Carbide (SiC) metal-oxide semiconductor field-effect transistors (MOSFETs) into advanced power modules. The new module significantly reduces losses in an electric drive system modeled after the Ford Focus, increasing vehicle fuel economy, range, and productivity. Figure 4(left) shows the advanced power module with SiC MOSFETs inside. Figure 4(right) shows comparison between a Si IGBT and Wolfspeed SiC MOSFET for traction drive operation. It is seen that the inverter losses are reduced by ~78% in electric-only drive mode for the EPA metro-highway cycle combined.

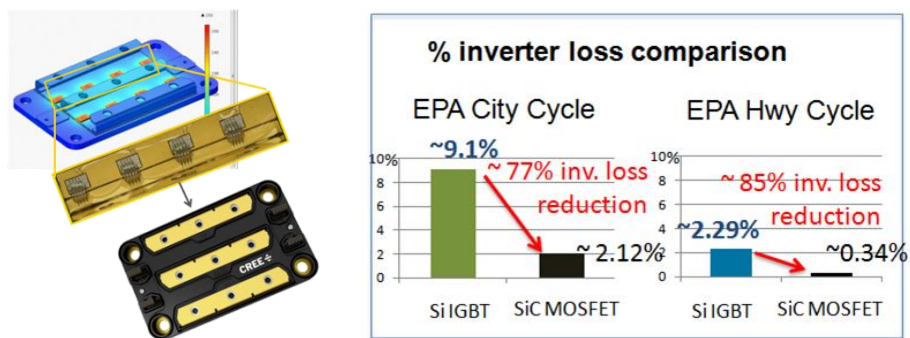


Figure 4: (Left) New 900V SiC MOSFETs. (Right) Comparison of losses for the 900V SiC MOSFETs power module vs. the Si IGBT power module, for a 90kW Ford Focus EV

## 2.2 Grid/Charging Infrastructure R&D

The objective of grid/charging infrastructure R&D is to research, develop, and demonstrate grid modernization technologies for a smooth transition to the mass adoption of EVs. It includes grid-based load control technology using vehicle-to-grid communication, vehicle-based reverse power flow technology, and evaluating the impact of grid-managed vehicle charging. It is concerned with mitigating adverse effects of EV deployment and leveraging existing synergy between EVs and the grid, building systems, distributed renewables, and other smart grid assets with a specific goal of understanding the cost and technical barriers to a HPC grid and charging infrastructure capable of charging an EV battery in 15 minute or less while providing 350+ kW in power (representing a three-fold improvement in performance). The *Codes & Standards R&D* supports timely development and adoption for grid connected vehicles in the areas of communications, connectivity, and charging and involves ANL, PNNL, INL, and LBNL. The *EV Smart Grid Interoperability Center* supports international harmonization. The *Zero Emission Cargo Transport (ZECT)* focuses on grid connected MD HD package delivery applications and the *Grid Modernization Laboratory Consortium (GMLC)* supports intelligent integration of EVs into the grid through four foundational projects, in the areas of control theory, testing network, grid services, New York State Energy Initiative; as well as four vehicle-specific projects on grid and building services from connected vehicles at building distribution and national levels, cyber security. Some highlights related to the grid integration R&D are as follows.

### **2.2.1 20kW Wireless Power Transfer (WPT) Technology with 90% efficiency**

A 20-kilowatt wireless charging system demonstrated at ORNL achieved 90 percent efficiency at three times the rate of the plug-in systems commonly used for current electric vehicles, which can help accelerate the adoption of EVs. Industry partners from Toyota, Cisco Systems, Evatran, and Clemson University International Center for Automotive Research contributed to the technology development at ORNL.

### **2.2.2 INL Bench Testing for Electric Vehicle Wireless Charging**

Idaho National Laboratory (INL) and six partner companies achieved a major milestone by completing bench testing for wireless charging systems. INL collaborated with Toyota, Nissan, WiTricity, Jaguar Land Rover, Qualcomm and an automaker to perform tests designed to allow charging pads from one company to work with the vehicle pads from another. This “interoperability” is important for safety and performance of wireless charging systems. Those tests help ensure that wireless charging systems meet minimum interoperability requirements for proper functionality, high efficiency and safety.

### **2.2.3 Evaluation of Thermal Load Reduction Technologies**

Climate control loads have a significant impact on electric drive vehicle (EDV) range, potentially cutting it by over 50% in both cooling and heating conditions. To minimize the impact of climate control on EDV range, NREL partnered with Hyundai America and key industry partners to quantify the performance of thermal load reduction technologies on a Hyundai Sonata plug-in hybrid electric vehicle. Technologies that impact vehicle cabin heating in cold weather conditions and cabin cooling in warm weather conditions were evaluated (see Figure 5).



Figure 5: NREL evaluated thermal load reduction technologies for a 2016 PHEV.

### **2.2.4 EVs Joining IoT at ANL Smart Energy Plaza**

Argonne National Laboratory’s (ANL) smart energy plaza facility enables realistic smart grid studies that combine its capabilities in grid modeling and simulation with internally-developed sensing, communication and control technologies. It integrates solar power and battery storage with smart charging and controllable building systems to minimize total energy use and operate as an isolated micro-grid if needed. The Smart Energy Plaza is primarily a development, testing and demonstration center for grid integration studies that include soon-to-be-introduced high-power DC and wireless charging in cooperation with the auto industry and charging equipment suppliers. ANL developed a grid services enabling technology and demonstrated the Common Integration Platform (CIP.io) and ‘Internet of Things’ (IoT) approach in this facility. The project software was published as open source interface code for components in the plaza.

### **2.2.5 EV Grid Integration at the Energy System Integration Facility**

NREL leads DOE’s Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project, which aims to enable energy efficiency, renewable power, and sustainable transportation technologies to increase the capacity, efficiency, and stability of the grid. NREL collaborates with automakers, charging station manufacturers, utilities, fleet operators, and other national laboratories to enable PEV communication with the smart grid and to create opportunities for vehicles to play an active role in building and grid management.

### 2.2.6 Smart Grid Interoperability Center

ANL houses the EV Smart Grid Interoperability Center (Figure 6) which plays a key role in supporting global harmonization of standards and technology for the EV-grid interface, as well as charging interoperability to enable future EVs and charging stations work seamlessly. ANL researchers provide support to emerging technology development in grid connectivity, bridging the needs of the EV manufacturers and the utilities. The focus of this research and development effort is in providing practical applications that enhance the market acceptance of plug-in vehicles and the charging infrastructure.



Figure 6: The EV-Interoperability Center at Argonne offers state-of-the-art tools to advance charging interoperability and global harmonization for electric vehicles.

### 2.2.7 Grid Modernization Lab Consortium (GMLC) Accomplishments

Project staff developed master requirements documents which will be used across VTO's GMLC projects and which describe a common set of vehicle charging demonstration use cases and communication and control requirements needed to demonstrate coordinated PEV charging under time-varying commercial building load conditions (minimizing demand charges) and form the technical basis for the interoperable vehicle charging demonstrations planned at ANL, NREL and PNNL. Project staff also began vehicle to building (V2B) systems engineering activities, finalized communication architecture and testing processes, and started preparations for demonstrating one standards-compliant, multi-vehicle, workplace charging use case. They also initiated systems engineering of grid services and renewable energy integration at the electric utility distribution level, started feasibility analysis of vehicle to grid integration (VGI) and began developing a diagnostic security module (DSM) framework for creating an end-to-end security architecture for the integration of a modern PEV with EV supply equipment and a building energy management system.

## 3 Advanced Batteries R&D

VTO has a successful track record of planning and executing R&D on critical battery technologies that move into commercial applications. Hybrid and electric vehicles on the market from GM, Ford, Fiat Chrysler, BMW, Mercedes, and Land Rover are using lithium-ion technologies which were developed under VTO funding. VTO cost-shares advanced batteries R&D projects via the United States Advanced Battery Consortium and supports battery R&D at the national laboratories under the applied battery research for transportation and advanced battery materials research activities [4]. DOE-funded research has helped reduce the current cost projection for an EV battery (for three DOE-supported battery developers) to an average \$245 per kilowatt-hour of useable energy (Figure 7). This cost projection is derived by using ANL's peer-reviewed public domain battery production and cost model (BatPaC), assuming a production volume of at least 100,000 batteries per year. DOE's goal is to continue to drive down battery cost to \$125/kWh by 2022.

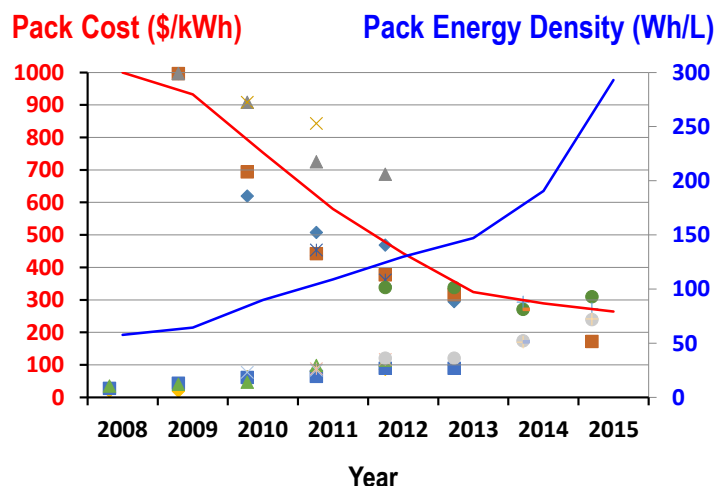


Figure 7: DOE R&D supported significant battery cost reductions (3X) since 2008.

VTO advanced batteries R&D can involve either short-term pre-competitive research by commercial developers or exploratory materials research generally spearheaded by national laboratories and universities. The *Advanced Battery Development* R&D activity focuses on the development of robust battery cells and modules to significantly reduce battery cost, increase life, and improve its performance and takes place in close partnership with the automotive industry, partially through a cooperative agreement with the United States Advanced Battery Consortium (USABC). DOE also works in close collaboration with USABC to develop battery performance targets for various applications: e.g., power-assist hybrid battery goals [5], EV battery goals [6], PHEV battery goals [7], as well as ultracapacitor performance requirements [8]. The *Battery Testing, Analysis, and Design* activity focuses on performance, life and abuse testing of contract deliverables, laboratory- and university-developed cells, and benchmark systems from industry; thermal analysis, thermal testing and modeling; development of tools for the computer aided engineering of batteries. Battery technologies are evaluated according to USABC-stipulated battery test procedures for relevant applications, for EVs [9], HEVs [10], or PHEVs [11]. Benchmark testing of an emerging technology is performed to remain abreast of the latest industry developments. The *Applied Battery Research* (ABR) activity is focused on the optimization of next generation, high-energy lithium-ion electro-chemistries that incorporate new battery materials. It emphasizes identifying, diagnosing, and mitigating issues that impact the performance and lifetime of cells constituted of advanced materials. The *Advanced Process Development* activity involves R&D on systematic material engineering and customized scaled processes to produce high quality material at kilogram-levels. The *Advanced Battery Materials Research* (BMR) activity addresses fundamental issues of materials and electrochemical interactions associated with lithium batteries, develops new/promising materials and uses advanced material models to discover such materials using scientific diagnostic tools/techniques. Many VTO *Small Business Innovation Research* (SBIR) contracts focus on the developing new battery materials and components. VTO has established extensive and comprehensive ongoing coordination efforts in energy storage R&D across all of the DOE complex, with other government agencies as well as international organizations.

### 3.1 Advanced Cell Materials and Designs

Working on a VTO-funded project, Farasis improved the capacity (and rate capability) of their Nickel Manganese Cobalt (NMC) materials for 4.4+V operation, using surface treatment and bulk-doping approaches, see Figure 8 (left). On an advanced cathode R&D project, TIAX developed long-life lithium-ion cells which exceed DOE energy and power targets (200Wh/kg and 800W/kg pulse power, respectively) for PHEV40 battery cells. The technology pairs a high capacity version of TIAX's proprietary high energy and high power CAM-7® cathode material with a blended anode containing Si and graphite materials. Prototype 18650 cells, with CAM-7 and the Si-based blended anode were built and tested, delivering higher specific energy and power than baseline cells employing CAM-7/graphite, as seen in Figure 8 (right).

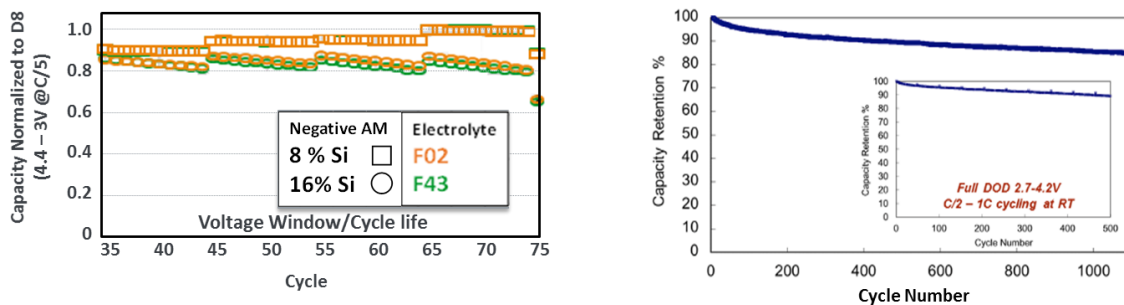


Figure 8: (Left) Farasis Gen2 EV testing cell performance, (Right) CAM-7/Si-based anode 18650 cells cycling.

### 3.2 High Voltage Electrolytes

ANL has developed a new class of electrolytes based on fluorinated carbonate solvents. Compared with conventional electrolytes, the fluorinated electrolyte shows much improved performance both in Coulombic efficiency and capacity retention at 55°C (Figure 9, left). Daikin has shown that while a typical hydrocarbon electrolyte is not suitable for battery operation above 4.35 V due to gassing and decomposition of the electrolyte, the introduction of fluorocarbons into the conventional electrolyte allows it to cycle up to 4.5V in 1 Ah NMC(111)/graphite cells. Figure 9, right, shows the cycle life of hydrocarbon and fluorocarbon electrolytes in 1 Ah NMC/Graphite cells at 4.2, 4.35, and 4.5 V.

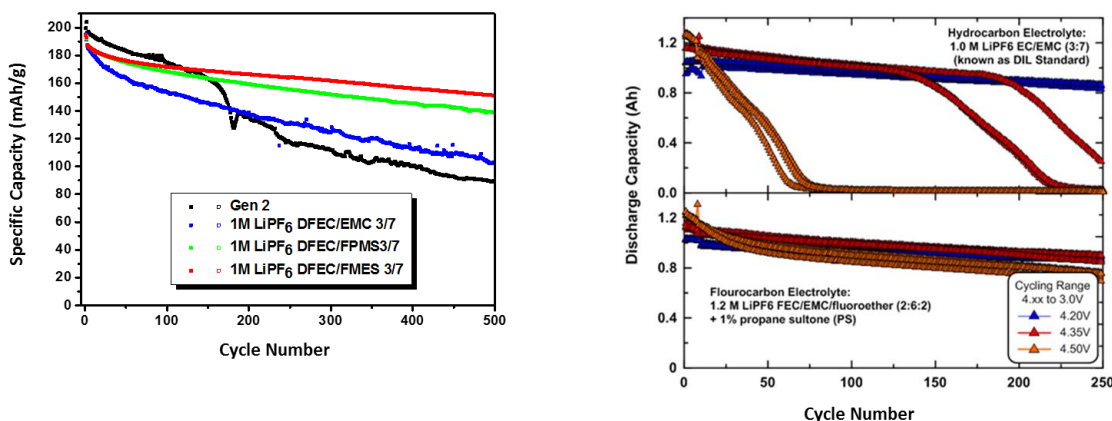


Figure 9: (Left) NMC532/Graphite cells with ANL fluorinated sulfones as additives, (Right) Daikin fluoro carbon electrolytes for high voltage operation.

### 3.3 Novel Processing Advances for Batteries

There have been several key advances in the area of advanced processing of batteries. Lambda Technologies showed that variable frequency microwave enables faster drying, especially in series with a traditional heater oven (which accelerates the evaporation of solvent from near surface regions). This technology has also shown great success in drying 200 micron electrodes, 100% thicker than what is currently feasible. ORNL has used e-beam curing to enable extremely fast drying of thick electrodes. PPG Industries showed extremely promising electrochemical performance of electrodeposited cathodes, which is significant because electrodeposition is an extremely high volume, energy and cost efficient process used to paint tens of millions of car bodies (figure 10). 24M demonstrated semi solid electrodes that enable building of cells with electrodes that are many times (4x-10x) thicker than current cells. Thicker electrodes reduce the weight, volume, and cost of non-energy storing materials like current collectors, separator, etc. (Figure 11.)

2.2Ah Li-ion cell (Graphite anode+NCM523 Cathode): Cycle Life at 80%DOD  
(Charge/discharge @C/3, Voltage window 3.5-4.2V)

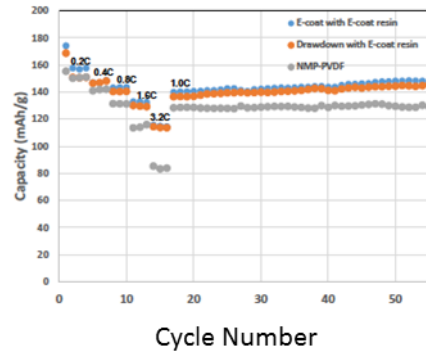
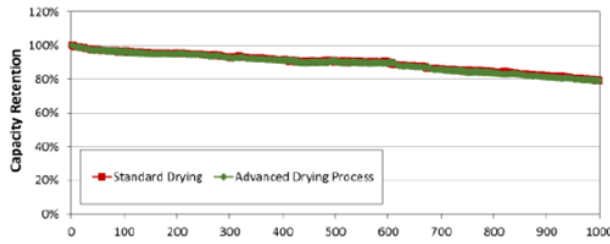


Figure 10: (Left) 2.2 Ah Li-ion cells from Lambda Technologies, (Right) Electrodeposition of Cathode materials, PPG Industries.

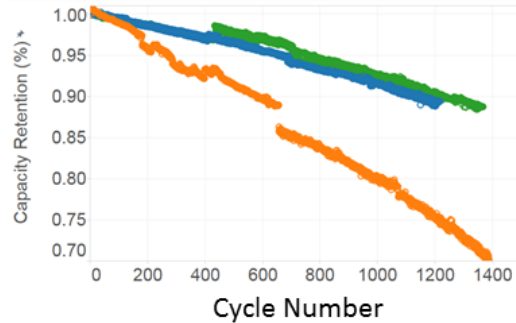
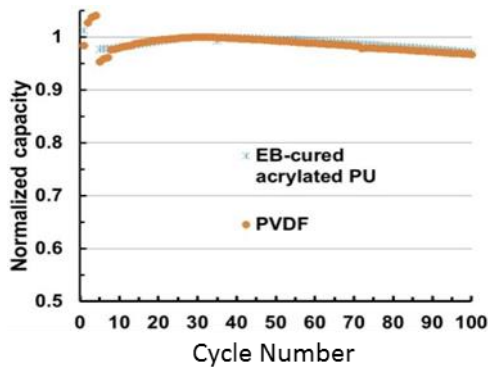


Figure 11: (Left) E-beam curing of cathode materials by ORNL, and (Right) Semi-solid electrodes performance, by 24M.

### 3.4 Beyond Lithium-ion R&D

Among the beyond-lithium-ion technologies, lithium metal anode has a capacity up to 10-fold higher than commercial graphite anodes materials but suffers from challenges of lithium dendrite growth (resulting in internal short circuits and possible thermal runaways), as well as poor cycling stability shortening cycle life. Stanford University has developed a new approach on Li metal anode design, constructing a “stable host” to reduce the anode’s volume change during cycling. To achieve this goal, an advanced nanotechnology structure is utilized as shown in microscopic images (a-c) in Figure 12. Here, the designed structure consists of stacked graphene layers with uniform nanoscale interlayer gaps. The gaps provide room for storing Li metal.

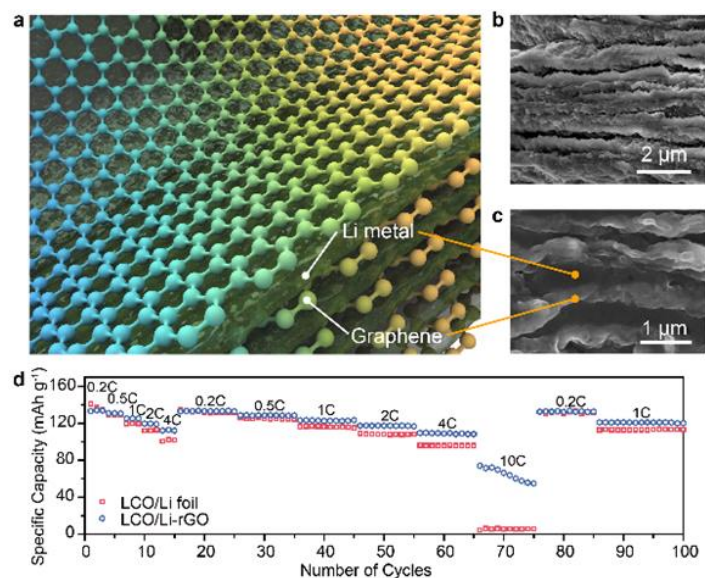


Figure 12: Schematic of the Li metal anode with “stable host”, which exhibits layered stacking of Li metal and graphene. (b,c), Scanning electron microscopy (SEM) images of the Li metal anode in cross-section view. (d) Cycling stability of Li-rGO and Li foil symmetric cells at 1 mA cm<sup>-2</sup> and 1 mAh cm<sup>-2</sup>

For another beyond-lithium-ion technology, lithium sulphur, Pennsylvania State University (PSU) researchers developed a functional electrolyte system using dimethyl disulfide (DMDS) as a co-solvent for such batteries. DMDS promotes the discharge of sulphur through an alternate electrochemical reaction pathway by formation and subsequent reduction of dimethyl polysulfide species. The new reaction pathway not only boosts cell capacity, but also improves electrochemical kinetics and reduces electrolyte amount. This work represents a major step towards lowering the electrolyte amount in Li-S batteries in order to increase future energy-density of Li-S batteries.

In solid-state electrolyte research, through modification of interfacial layers (obtained via computational modelling and controlled interfacial structures by 3D printing) the University of Maryland has achieved a low interfacial resistance in cells with a solid ceramic electrolyte comparable to commercial flammable liquid electrolyte batteries. This solves the significant issue of “large interfacial resistance” for solid-state batteries. The research team used atomic layer deposition to place a thin film of aluminium oxide on top of the solid ceramic structure.

### 3.5 Battery Safety R&D

National Renewable Energy Laboratory’s (NREL’s) Battery Internal Short Circuit (ISC) Device, the first sensor able to accurately simulate an internal short circuit within a lithium-ion cell, received the prestigious *R&D 100 Award* in 2016. The NREL device, as shown in Figure 13, allows battery developers to evaluate the effectiveness of new materials and cell designs to assess and address hazards and enhance battery safety. CT imaging provides unprecedented insights into the failure mechanisms in 18650 cells after initiation of the NREL ISC Device. In 2016, NREL received over 1,000 orders from NASA and three different battery manufacturers for the ISC Device to improve safety of lithium-ion batteries.

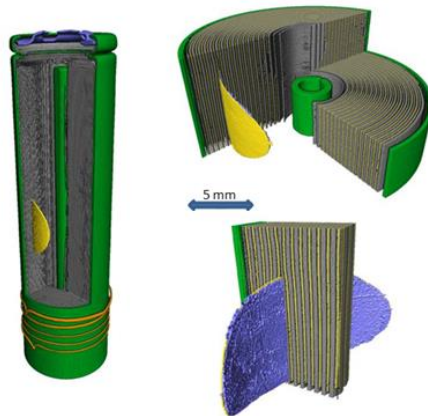


Figure 13: Computerized tomography (CT) rendering of Battery ISC Device inside a lithium-ion battery. The yellow and blue portion of the image is the ISC device in an 18650 cell. (Source: University College of London)

### 3.6 New Focused Research Activities in Batteries

Fast-charging can lead to increased utility of battery electric vehicles providing greater choices in mobility and the ensuing energy security. With charging rates up to 350kW allowing for more convenient EV “refueling”, cost targets may no longer remain the sole metric for consumer adoption of EVs. The implementation of direct current fast-charging (DCFC), at these increased rates is expected to impact many technology areas. The *Extreme Fast Charging (XFC)* research attempts to understand the cost and technical barriers associated with implementing the 350kW direct current fast-charging of EVs. It has been generally recognized that a combination of fast charge batteries and a network of high capacity chargers can minimize range anxiety and promote the market penetration of BEVs and increase total electric miles driven. In September 2016, VTO-organized a stakeholder workshop (held at NREL) to discuss issues related to fast-charging to assess the knowledge base of the fast charging capability of automotive batteries, identify technical gaps for fast charging to identify R&D opportunities. Based on the findings of the workshop, a study [12] was prepared listing an issue tree and potential major obstacles and possible solutions. The issues identified regarding fast charging included higher cost cells (nearly twice compared to today’s lithium-ion cells), cycle life & durability of cells, lithium plating/deposition occurs on the anode above a threshold current density, and cell temperature rise during fast charging; each of which could be possible R&D areas.

The newly-started VTO *Battery500 consortium* includes the Pacific Northwest National Laboratory, Brookhaven National Laboratory, Idaho National Laboratory, SLAC National Accelerator Laboratory, Binghamton University, Stanford University, University of California at San Diego, University of Texas at Austin, University of Washington, and (in advisory capacity) the International Business Machines. The consortium has the aggressive goal of developing a battery cell with a specific energy of 500Wh/kg, compared to the 200Wh/kg in today’s typical EV battery [13]. These goals require focusing on lithium-metal batteries, which use lithium instead of graphite for the battery’s negative electrode; pairing lithium with two different materials for the battery’s positive electrode.

In the *Silicon Electrolyte Interface Stabilization (SEISta)* activity, intermetallic anodes offer attractive performance targets (current densities of 1,000+ mAh/g and life of 1000 cycles) but face challenges of large first-cycle irreversible loss, low calendar life/high capacity fade, poor coulombic efficiency, and an inferior power capability. Addressing those challenges requires developing a stable SEI layer for the silicon anodes and developing a more foundational understanding of the formation and evolution of the SEI on silicon.

### 3.7 Lithium-ion capacitors (Maxwell Technologies/USABC)

In FY2016, Maxwell Technologies announced the first commercial application of lithium-ion capacitors (LIC) for rapid energy regeneration in a trolley system for a large rail manufacturer in China. This technology was initially developed under a USABC program and is based on an asymmetric supercapacitor LIC (in which one electrode stores charge exclusively like a classical capacitor while the other stores lithium ions like in a battery).

### 3.8 Advanced battery development awards

In FY 2016, VTO awarded 14 advanced batteries projects totalling \$16.4 million in the areas of high-voltage electrolytes, solid-state electrolytes, lithium metal protection, advanced characterization techniques and advanced battery material modelling [14], all of which have FY 2017 start dates.

## 4 Optimizing Opportunities for Energy Savings

The Energy Efficient Mobility Systems (EEMS) program within VTO aims to identify and support technologies and innovations that encourage a maximum-mobility, minimum-energy future in which transportation systems may be automated, connected, electric, and/or shared (ACES). EEMS supports R&D that investigates how disruptive forces such as ACES will impact energy consumption in transportation. It also helps communities determine how they can plan for and encourage energy efficiency increases in mobility. For example, a VTO-funded paper [15] showed that the disruptions from connectivity and automation to the transportation sector could result in a potential 200% increase in 2050 baseline energy consumption or, under different scenarios, even a 60% decrease in energy use. Increases could be caused by many factors, including easier travel and more accessibility, whereas harnessing connected and automated technologies to enable ride sharing, drive smoothing, and vehicle resizing, could decrease energy consumption. EEMS coordinates its works with electrification R&D managers within VTO as well as with researchers and different stakeholders and communities to better understand how to make use of ACES technologies to make mobility more energy efficient – operating in a continuous feedback loop between R&D analyses and modelling, and real-world living labs to identify the best system-level opportunities to significantly increase the energy efficiency of the movement of people and goods.

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