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An Overview of the US-DOE Batteries & Electrification Program R&D for FY 2018-19

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Summary

This paper provides the fiscal year (FY) 2018-19 status overview of R&D efforts of the batteries & electrification (B&E) program in the Vehicles Technologies Office (VTO) of the U.S. Department of Energy (DOE). B&E research covers a number of areas including electric drive technologies, grid integration, and advanced batteries. There exists a significant long-term U.S. commitment to B&E systems R&D – the FY 2019 budget for this program approaches ~$163 million. Status updates on B&E R&D efforts have been regularly provided at prior EVS meetings. Current research spans a number of areas including electrification and advanced batteries. The paper will discuss the associated VTO B&E programmatic structure; current research thrusts and recent key accomplishments for each area.

Keywords: battery, electric drive, EV (electric vehicle), energy storage, charging

1 Introduction

The DOE Vehicle Technologies Office (VTO) in the Office of Energy Efficiency and Renewable Energy (EERE) invests in early-stage research to enable development and commercialization of affordable, energy efficient transportation. One of the major VTO objectives is to enable U.S. innovators rapidly develop the next generation of technologies that achieve the cost, range, and charging infrastructure necessary for the widespread adoption of plug-in electric vehicles (PEVs). An important prerequisite for the electrification of the nation's light duty transportation sector is development of more cost-effective, longer lasting, and more abuse-tolerant PEV batteries. One of the ultimate goals of this research, and currently a strong trend in vehicle electrification, is an EV which can provide the full driving performance, convenience, and price of an internal combustion engine (ICE) vehicle. To achieve this, VTO has established the following overarching goal:

> "VTO supports early-stage R&D to identify new battery chemistries or a new cell technology with the potential to reduce the cost of electric vehicle batteries by more than half to less than $100/kWh and increase the range to 300 miles while decreasing the charge time to less than 15 minutes by 2028."

The cost target supports a levelized cost of driving of a 300-mile BEV at $0.28/mile, which is comparable to that for future ICE vehicles at $0.27/mile. The ultimate cost goal for a 300-mile BEV battery is $80/kWh, which would approach $0.26/mile.

VTO goals include reducing the production cost of a BEV battery to $80/kWh, increasing the range of electric vehicles (EVs) to 300 miles, and decreasing their battery charge time to 15 minutes or less. This is a long-term R&D program, status reports for which have been presented in several prior EVS meetings (e.g., [1], [2]).

Stakeholders for the VTO R&D activities include universities, national laboratories, other government agencies and members of industry including automakers, battery manufacturers, material suppliers, component developers, private research firms, and small businesses. VTO works with key U.S. automakers through the United States Council for Automotive Research (USCAR) – an umbrella organization for collaborative research consisting of Fiat Chrysler LLC, the Ford Motor Company, and the General Motors Company. Collaboration with automakers through the partnership known as U.S. Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability (US DRIVE) attempts to enhance the relevance and the potential for success of the research portfolio.

VTO collaborates with industry partners and other stakeholders through partnerships (e.g., the U.S. DRIVE [3]), to accelerate the development of advanced transportation technologies, including advanced batteries and electric drive systems. Battery & electrification program R&D includes research on electric drive technologies, advanced batteries, grid integration, and extreme fast charging (XFC). The FY2019 budget for battery and electrification (B&E) R&D was approximately $163 million (including $110 million for batteries, $22 million for electric drive technologies, and $31 million for grid and infrastructure). The organizational structure of VTO is shown in Fig. 1.

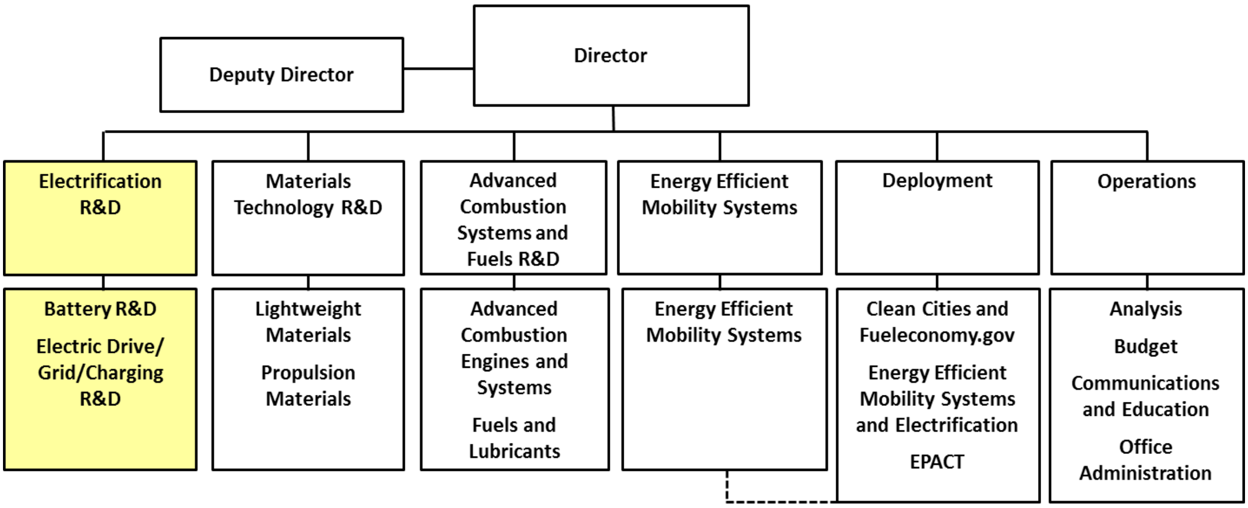

Fig. 1 Organization chart for the DOE Vehicle Technologies Office (VTO)

VTO competitively awards funding through funding opportunity announcement (FOA) selections, and projects are fully funded through the duration of the project in the year that the funding is awarded. Directly−funded work at the national laboratories (also awarded competitively through a lab-call process) is subject to change based on annual appropriations. During the past year, VTO continued R&D in support of PEVs such as plug-in hybrid electric vehicles (PHEV), extended range electric vehicles (EREV), and all-electric vehicles (EVs), as well as some conventional hybrid electric vehicle (HEV) technologies, particularly the 12 volt start/stop hybrid.

During fiscal year 2018-19, VTO funded early stage research & development (R&D) projects that address Batteries and Electrification of the U.S. transportation sector. The VTO Electrification Sub-Program is composed of Electric Drive Technologies and Grid Integration activities. The Electric Drive Technologies group conducts R&D projects that advance Electric Motors and Power Electronics technologies. The Grid and Charging Infrastructure group conducts R&D projects that advance Grid Modernization and Electric Vehicle Charging technologies.

2 Battery & Electrification (B&E) Program Areas

2.1 Low-cost/Fast-charge Batteries

Recharging current EV batteries takes much longer than refueling the average liquid-fueled internal combustion vehicle. However, charging at too high a rate runs the risk of lithium plating, increased battery temperature, and other detrimental chemical reactions which decrease life and performance of the batteries. It has been estimated that EVs could be received more favorably by the general population if their charging stations could sufficiently recharge their battery (to provide approximately 200 additional miles of driving) in under 10 minutes – something that can be accomplished via XFC, which could operate at power levels approaching 400kW. However, this introduces a host of new challenges that then have to be addressed. To characterize those challenges (and possible solutions), a multi-national laboratory team consisting of Argonne National Laboratory (ANL), Idaho National Laboratory (INL), and the National Renewable Energy Laboratory (NREL) engaged with industry stakeholders. Industry perspectives on XFC were used to develop a technology gap assessment report [4] to inform results of an extensive literature review, and use-cases for the economic feasibility of XFC. In April 2018, DOE announced $19 million to support twelve new cost-shared research projects focused on developing EV systems that can recharge rapidly and decrease charge times to 15 minutes or less using a connector or wireless fast charging system [5].

2.2 Grid & Infrastructure

The objective of Grid Systems R&D at VTO is to research grid modernization technologies for a smooth transition to mass adoption of EVs and grid-based load control technology using vehicle-to-grid communication, vehicle-based bidirectional power flow, and impact evaluations. It is concerned with mitigating adverse effects of EV deployment and leveraging existing synergy between EVs and the grid, building energy management systems, distributed renewables, and other smart grid assets. More information is available in the VTO Electrification Annual Progress Report [6].

2.3 Behind the Meter Storage (BTMS)

The behind the meter storage (BTMS) initiative is a multidisciplinary research effort to develop innovative battery energy storage technologies in the 1-10 MWh range to eliminate potential grid impacts of high power EV charging systems, and lower operational costs for users, behind utility meters. BTMS systems face different calendar-life, cycle-life, and cost challenges from EV systems and also have different balance-of-plant ratios; so their design and cost parameters need to be optimized differently. Four national labs are participating in this research.

2.4 Electric Drive Technologies

The Electric Drive Technologies (EDT) program's mission is to conduct early stage research and development on transportation electrification technologies that accelerate the development of cost-effective and compact electric traction drive systems that meet or exceed performance and reliability requirements of internal combustion engine (ICE)-based vehicles, thereby enabling electrification across all light-duty vehicle types.

The goal of the EDT program is to develop an electric traction drive system at a cost of $6/kW for a 100 kW peak system by 2025. In addition, the program has a 2025 power density target of 33 kW/L for a 100 kW peak system. While achieving these targets will require transformational technology changes to current materials and processes, it is essential for enabling widespread electrification across all light-duty vehicle platforms.

2.5 Battery Technology R&D

The advanced cell and battery R&D activity focuses on the development of robust batteries to significantly reduce battery cost, increase life and performance. A large part of this effort occurs in close partnership with the automotive industry, through a cooperative agreement with the U.S. Advanced Battery Consortium. The Advanced Battery Materials (BMR) R&D activity addresses fundamental issues of materials and electrochemical interactions associated with rechargeable automotive batteries [7]. More recently, VTO is funding the Battery500 Consortium [8], with the aggressive goal of developing a battery cell with a specific energy of 500Wh/kg. VTO also sponsors research to develop recycling processes for battery materials.

To quantify the improvements needed to accelerate large-scale adoption of PEVs and HEVs, certain performance and cost targets have been established. Some sample performance and cost targets for EV batteries, both at cell level and at system (pack) level, are shown in Table 1.

Table 1: Subset of EV requirements for batteries and cells

Energy Storage Goals (by characteristic)	Pack Level	Cell Level
Cost @ 100k units/year (kWh = useable energy)	$100/kWh*	$75/kWh*
Peak specific discharge power (30s)	470 W/kg	700 W/kg
Peak specific regen power (10s)	200 W/kg	300 W/kg
Useable specific energy (C/3)	235 Wh/kg*	350 Wh/kg*
Calendar life	15 years	15 years
Deep discharge cycle life	1000 cycles	1000 cycles
Low temperature performance	>70% useable energy @C/3 discharge at -20°C	>70% useable energy @C/3 discharge at -20°C
	*Current commercial cells and packs not meeting the goal	

The *Advanced Cell and Battery Research and Development* activity focuses on the development of robust battery cells and modules to significantly reduce battery cost, increase life, and improve performance. Part of this effort occurs in close partnership with the automotive industry, through a cooperative agreement with the USABC. In FY 2018, via the USABC, VTO supported 11 cost-shared contracts with developers to further the development of PEV and HEV batteries and battery components. The estimated DOE share of those USABC contracts (over the life of the contracts) is approximately $39M. In addition to the USABC projects listed above, VTO also supports multiple *advanced processing* projects: including four battery and material supplier R&D projects which are funded/administered by the National Energy Technology Laboratory (NETL) and eight projects at the national labs and universities. Most strategies for increasing the performance and reducing the cost of lithium-ion batteries have focused on novel battery chemistries, material loading modifications, and increasing electrode thickness. Increasing electrode thickness is a known approach for increasing energy density (and in turn, the overall cell capacity). However, practical thicknesses are constrained by ionic transport limitations that occur with the increased thickness, limiting the cell power – as well as encountering processing issues. The estimated value of those advanced processing projects (over project lifetime) is approximately $35M. The advanced cell and battery research activity also includes several projects categorized under the *Computer Aided Engineering for (Electric-Drive Vehicle) Batteries* (CAEBAT) Program – which recently evolved into the Advanced Computer Aided Battery Engineering Consortium. The Consortium seeks to enable safer design of batteries by enhancing the predictive capability of computationally efficient electrochemical models for mechanical/electrochemical/thermal simulation models of battery physiochemical processes (in the event of a vehicle crash or internal short/thermal runaway). The participants include the National Renewable Energy Laboratory (NREL), Argonne National Laboratory (ANL) and Sandia National Laboratories (SNL). The consortium for advanced battery simulation (CABS) is an integrated partnership between Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), and SNL. Its projects highlight new experiments to develop constitutive relations for mechanical response of constituent materials, effective transport properties for electrochemical behavior of electrodes under deformation, and coupled simulations at layer-resolved scale to predict the behavior of the damaged batteries. The approximate value of the CAEBAT and associated programs is $14M.

The *Recycling and Sustainability* activity involves studies of the full life-cycle impacts and costs of Li-ion battery production/use; cost assessments and impacts of various recycling technologies; and the available material and cost impacts of recycling and secondary use. The participants include ANL and NREL and the associated value is approximately $10M.

The Advanced Materials Research & Development activity addresses fundamental issues of materials and electrochemical interactions associated with rechargeable automotive batteries. It develops new/promising materials and it makes use of advanced material models to discover such materials (and their failure modes), utilizing scientific diagnostic tools and techniques to gain insight into the failure process. The researchers belong to various national labs, universities, and industry partners. The work spans mainly two general areas –"next gen" chemistries (which employ an alloy anode and/or a high voltage cathode) and beyond lithium-ion (BLI) chemistries (which employ a lithium metal anode).

3.2 Battery500 Consortium

As part of the beyond lithium-ion effort, VTO funds the Battery500 consortium, a team consisting of Pacific Northwest National Laboratory, Brookhaven National Laboratory, Idaho National Laboratory, Stanford University/SLAC National Accelerator Laboratory, Binghamton University, University of California at San Diego, University of Texas at Austin, University of Washington, and in advisory capacity, International Business Machines, Tesla, National Alliance for Advanced Technology Batteries (NAATBatt), FMC, and USABC. 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. Achieving this goal would result in a smaller, lighter and less expensive battery. The team hopes to reach these goals by focusing on lithium-metal batteries, which use lithium instead of graphite for the battery's negative electrode. The team will pair lithium with two different materials for the battery's positive electrode.

3 B&E Program Highlights for FY 2018-19

This section contains brief descriptions for some recent key R&D highlights from the battery and electrification program. For more details on the associated projects, as well as for information on additional R&D projects, one can refer to the 2018 annual progress report publications for electrification [6] and that for batteries [7].

3.1 Novel integrated wireless EV charging architecture for wireless chargers (ORNL)

ORNL proposed an integrated wireless charger architecture, which utilizes the existing traction inverter and the DC link capacitor of the electric drive train as the secondary side rectifier of the wireless BEV charging system. This leads to increased power density, specific power, and reduced cost. An optimized interoperable double D coil pair was also designed and prototyped to facilitate in validation of the proposed integrated wireless charging architecture. (See Fig. 2.)

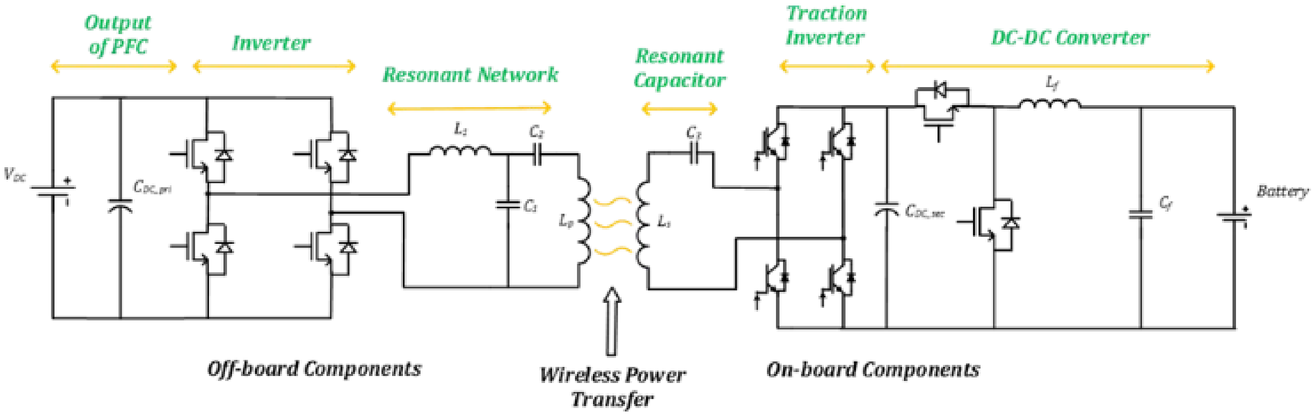

Fig. 2 Schematic of the integrated wireless BEV charging architecture proposed by ORNL

ORNL developed an 11-kW integrated wireless charging system, which utilizes a 2016 BMW i3 traction inverter to be used as the secondary side rectifier of wireless BEV charging system. The prototyped integrated wireless EV charging architecture was validated experimentally for 12-kW operation for a coil-t0-coil gap of 165.1 mm (6.5 inches). The dc-to-dc efficiency of the integrated wireless charging system without the motor connected was 91.8 % and with the motor connected was 88.96 %.

3.2 Characterization and Model for Electric Machine Lamination Materials and Interfaces (NREL)

Silicon steel lamination materials are critical to the construction and operation of inductors for power systems and electric motors. NREL developed a procedure to experimentally characterize layered materials, and it was applied to the silicon steel laminations. Using the experimental results, a model was developed that provided a good prediction for the interlamination contact resistance and the through-stack thermal conductivity. The work was recently published [9]. These results fill a current need for material property data and models specific to electric machine design that currently does not exist in the public/open literature. The data and modeling approach is especially useful for simulating heat extraction axially through the lamination materials within the machine, which is particularly important for cooling rotors used in permanent-magnet machines. (See Fig. 3.)

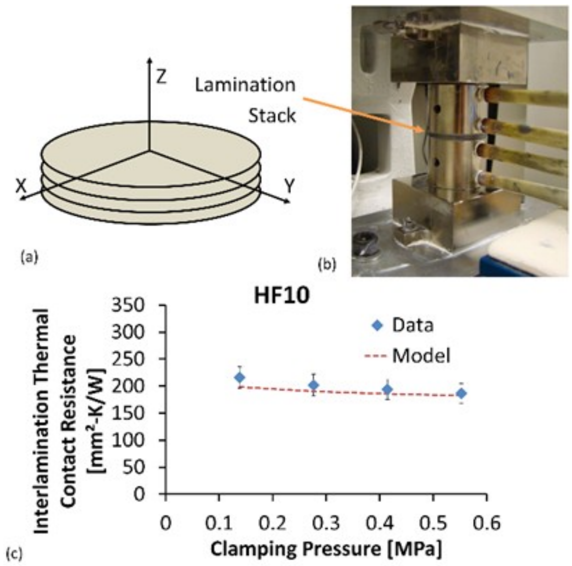

Fig. 3 (a) Orthotropic thermal property orientation for machine laminations. (b) Experimental setup (Photo Credit: NREL). (c)Results predicted by the model compared to the experimental data for one example sample material.

3.3 New cooling technology to enable a 100 kW/L inverter (NREL)

NREL has developed through thermal and computational fluid dynamics (CFD) modeling a novel power electronics cooling concept predicted to enable achieving the 100 kW/L power density target. The cooling concept is unique (i.e., not used in automotive cooling systems) and is predicted to provide better thermal performance as compared with current automotive technology (~50% lower thermal resistance than the on - road technology). The cooling concept and planar module design also eliminate the need for thermally conductive ceramics (e.g., silicon nitride) which are expensive and prone to thermomechanical failures, especially at high-temperature conditions (≥ 200°C). (See Fig. 4.)

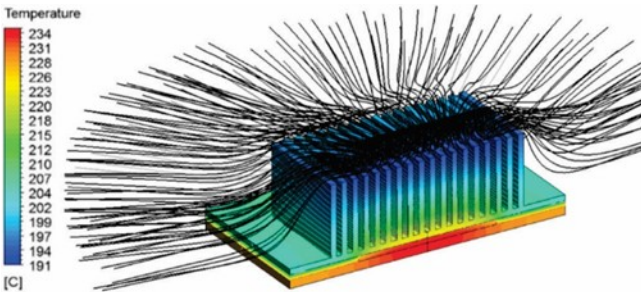

Fig. 4 CFD-computed temperatures for the 2.5-mm-tall fins configuration and jet velocity of 0.5 m/s predicted to enable reaching the 100 kW/L power density target.

3.4 Open-source modeling tool for high throughput optimization of electric motors (ORNL)

ORNL is developing an open source high performance computing toolkit for electric motor modeling and optimization called the Oak Ridge Toolkit for Electromagnetic Devices (OeRSTED). The toolkit is scalable from workstations to the DOE high-performance computing (HPC) resources for high-throughput optimization of electric motors. Increasing throughput is achieved by developing analysis methods for quickly characterizing motor designs on single nodes/workstations and researching new and improved evolutionary optimization methods for simultaneous analysis of multiple designs. (See Fig. 5.)

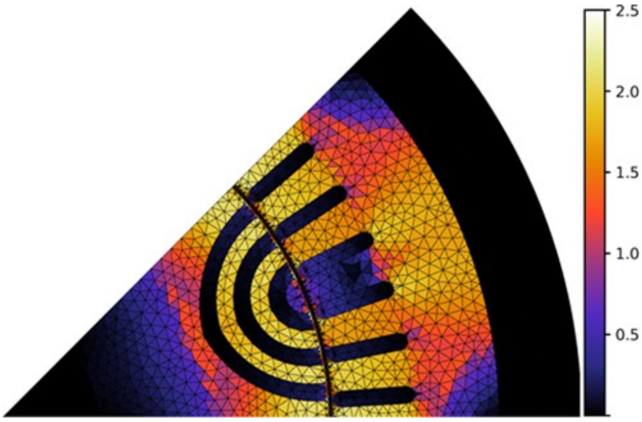

Fig. 5 Magnetic flux density distribution in a 1/8th section model of a permanent magnet free synchronous reluctance electric motor simulated using the Oak Ridge Simulation Toolkit for Electromagnetic Devices (OeRSTED)

3.5 Battery cost reduction

The 2018 DOE PEV battery cost reduction milestone of $200/kWh was accomplished. DOE-funded research has helped reduce the current cost projection for an EV battery (for three DOE-funded battery developers) to an average of $197/kWh of useable energy. This cost projection is calculated using ANL's public domain Battery Production and Cost model (BatPaC). It assumes a production volume of at least 100,000 batteries per year, the batteries meeting DOE/USABC system performance targets. DOE's goal is to continue to drive down battery cost to $100/kWh by 2028.

3.6 Extreme Fast Charging in enhanced Li-ion systems

Extreme fast charging of EV batteries would provide a refueling experience similar to conventional gasoline powered vehicles. Research in this area started with a 2017 research project to understand XFC. More recently, DOE awarded nine projects to develop cells with EV energy densities but that are also capable of being fast charged. The projects awarded are shown in Table 2.

Table 2: Extreme Fast Charging Project Awards

Awardee	Description	Funding
The Regents of the University of California, University of California San Diego	Research surface-acoustic wave turbulent electrolyte mixing during charging to enable rapid charging.	$653,641
Pennsylvania State University	Research advanced battery cell designs and strategies to operate and improve life and fast charging at higher temperatures.	$1,000,000
Regents of the University of Michigan	Research three-dimensional hierarchical graphite architectures for anodes for fast charging.	$1,500,000
SLAC National Accelerator Laboratory	Research on an advanced electrolyte and optimized cell design to enable extreme fast charging.	$1,500,000
Oak Ridge National Laboratory	Novel electrolyte research that increases the transport rate of lithium-ion from cathode to anode.	$900,000
Microvast, Inc.	Develop new electrolyte additives, optimized active materials, and electrode formulations.	$1,500,000
The Research Foundation for the SUNY Stony Brook University	Research to control lithium deposition over-potential on metal-coated graphite electrodes.	$800,000
University of Tennessee	Research on high power, doped titanium-niobium oxide anodes.	$720,000
Coulometrics, LLC	Research advanced battery cell designs with lower resistance to enable extreme fast charging.	$1,000,000

3.7 Low Cobalt/No Cobalt cathode projects

Recognizing the issues of price volatility and supply reliability with cobalt, in 2018, DOE awarded six new projects to develop and optimize low cobalt cathode materials. The projects awarded are listed in Table 3.

Table 3: Low Cobalt/No Cobalt Project Awards

Awardee	Description	Funding
Cabot Corporation	Aerosol manufacturing technology for production of low-cobalt lithium-ion battery cathodes	$2,989,057
NexTech Materials, Ltd. dba Nexceris, LLC	Cobalt-free lithium manganese nickel titanium oxygenate spinel cathodes for next generation lithium-ion batteries	$2,466,547
Oak Ridge National Laboratory	Cobalt-free aluminium iron nickelate cathode materials for next generation lithium-ion batteries.	$2,100,000
Penn State University Park	High-performance coated low-cobalt cathode materials for lithium-ion batteries	$1,952,017
University of California: San Diego	Cobalt free cathode materials and novel architectures	$2,500,000
University of California: Irvine	Enhancing oxygen stability in low-cobalt cathode materials	$2,500,000
University of Texas at Austin	High-nickel cathode materials for high-energy, long-life, low-cost lithium-ion batteries	$2,400,000

3.8 Recycling R&D Center

DOE launched the ReCell Battery Recycling R&D Center, a $4M/year effort by a multiple lab consortium with ANL, NREL, and ORNL which will focus on novel approaches to recycling to maximize economic yield of batteries at their end of life. This is expected to increase the rate of recycling for lithium-ion batteries and decrease dependence on foreign sources for critical materials. The focus areas of the ReCell Center include direct recovery of cathode material, separation methods, battery design for recycling, recovery of other materials, and advanced characterization of recycled material.

3.9 Battery500 Cell Achieves 310Wh/kg and 275 cycles, 350Wh/kg and 150 cycles

The Battery500 team succeeded in preparing rechargeable Li metal batteries that achieved 275 cycles with an initial specific energy of 310 Wh/kg. A second generation Li metal/NMC811 cell that is currently cycling shows a beginning of life (BOL) specific energy of 350Wh/kg and has reached 150 cycles of operation with less than 10% capacity fade (see Fig. 6). PNNL prepared the cells and INL performed validation and electrochemical analysis.

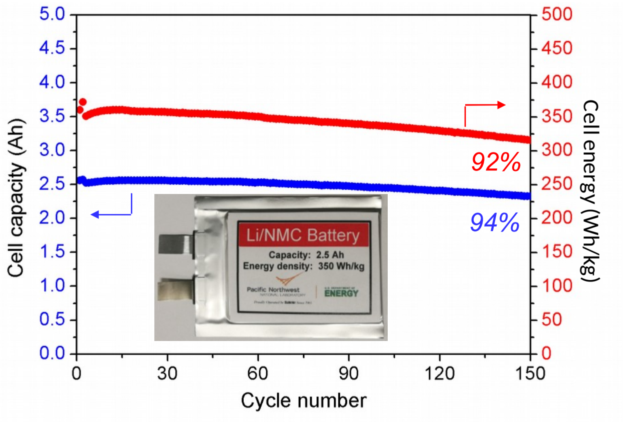

Fig. 6 Cell capacity (blue) and the energy (red) of a 2.5 Ah pouch cell as a function of cycling. The cell energy was measured based on the weight of the whole pouch cell including all cell components. The cell was charged within 10 hours (C/10) and discharged within 3 hours (C/3).

3.10 Lithium Battery Recycling Prize

Currently, lithium-ion batteries are only collected and recycled at a rate of less than 5% [10]. Recycled material could potentially provide one-third of US cathode material needs for lithium-ion batteries by 2030 [11]. The current infrastructure for collecting, storing, transporting and recycling of lithium-ion batteries is limited, particularly for larger batteries used in EVs and industrial applications. This is unlike lead-acid batteries' infrastructure which has resulted in 99% collection and recycling of lead acid batteries. To address the lack of a well distributed, efficient, and profitable infrastructure to enable recycling of lithium-ion batteries, DOE VTO has established a Battery Recycling Prize (amounting to $5.5-million) to incentivize American entrepreneurs to find innovative solutions to solve current challenges associated with collecting, storing, and transporting spent or discarded lithium-ion batteries for eventual recycling. The goal of the Battery Recycling Prize is to develop innovative business and technology strategies with the potential to capture 90% of all lithium-based battery technologies (consumer electronics, stationary, and transportation applications) in the United States; and that make collecting, sorting, storing, and transporting lithium-based batteries safe, efficient, and profitable.

The prize will facilitate entrepreneurs to leverage the resources of incubators, universities, and the national labs to transform innovative early-stage concepts into prototypes primed for industry adoption. Successful concepts must consider cost-effective methods or technologies such as separation and sorting of various collected battery types and sizes; rendering lithium-based batteries safe or inert during storage; or reducing the hazardous classification of lithium-based batteries in order to reduce shipping costs.
The three consecutive innovation phases of the Battery Recycling Prize (see Fig. 7) will accelerate entrepreneurs' efforts to create disruptive solutions to collect, store, and transport 90% of spent or discarded lithium-ion batteries. In each phase, the winners are determined by a panel of expert judges evaluating concepts based on feasibility, cost to implement, and potential impact.

Fig. 7 The areas of interest for the Lithium-ion Battery Recycling Prize.

4 Summary & Conclusions: Optimizing Energy Saving Opportunities

The B&E program has had a long-term, successful track record of successes in advancing the state of the art of advanced automotive batteries and electric drive technologies, successful commercialization of various electric drive technologies (especially batteries), and in bringing down the projected cost of battery technologies. Besides the R&D described above, VTO has established extensive and comprehensive ongoing coordination efforts in energy storage R&D across all of the DOE complex and with other government agencies. It coordinates efforts on energy storage R&D with both the Office of Science and the Office of Electricity. Coordination and collaboration efforts also include membership and participation in the Chemical Working Group of the Interagency Advanced Power Group (IAPG), in program reviews and technical meetings sponsored by other government agencies, and inviting participation of representatives from other government agencies in the contract and program reviews of DOE-sponsored efforts. DOE coordinates such activities with the Army's Advanced Vehicle Power Technology Alliance, the Department of Transportation/National Highway Traffic Safety Administration (DOT/NHTSA), the Environmental Protection Agency (EPA), and the United Nations Working Group on Battery Shipment Requirements. Additional international collaboration occurs through the International Energy Agency's (IEA's) Hybrid Electric Vehicles Technology Collaboration Program (HEV TCP); the G8 Energy Ministerial's Electric Vehicle Initiative (EVI); and bilateral agreements between the U.S. and China. The U.S. China Clean Energy Research Center conducts collaborative research both on rechargeable lithium-ion and beyond lithium-ion battery technologies to help develop the next generation of advanced batteries to help expand electrification of vehicles and enable smart grids internationally and its main objective is to understand and develop advanced battery chemistries based on lithium-ion and beyond lithium ion that meet 300Wh/kg energy density.

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Authors

Steven Boyd has worked for the Vehicle Technologies Office at the U.S. Department of Energy since 2006. As Program Manager for Batteries and Electrification, Steven manages projects for energy storage, electric drive systems, and vehicle charging. This research focuses on early-stage R&D to identify new battery chemistry and cell technology with the potential to reduce the cost of electric vehicle batteries by more than half, address the potential impacts of electric vehicle (EV) charging on the Nation's electric grid, and develop extreme high power density motor and power electronics that have the potential to enable radical new vehicle architectures. Steven received his Bachelor of Science and Master of Science degrees in Mechanical Engineering from Virginia Tech, and has participated in DOE's Advanced Technology Vehicle Competitions as a student and organizer..

David Howell is the Deputy Director of the DOE Vehicle Technologies Office and the Acting Program Manager for the Electrification Systems Program. Earlier, he was the Aerospace Technologies project manager at the Oak Ridge National Laboratory and before that, served on active duty for 6 years at the Wright Patterson AFB, Ohio, as the program manager for Advanced Materials for Space Structures at the Air Force Materials Laboratory. He received his B.S. degree in Aerospace Engineering from the University of Tennessee, Knoxville, TN.