2. Battery R&D

The Vehicle Technologies Office (VTO) supports research, development, deployment, and demonstration (RDD&D) of new, efficient, and clean mobility options that are affordable for all Americans. The office's investments leverage the unique capabilities and world-class expertise of the national laboratory system to develop new innovations in vehicle technologies, including: advanced battery technologies; advanced materials for lighter-weight vehicle structures and better powertrains; energy-efficient mobility technologies and systems (including automated and connected vehicles as well as innovations in connected infrastructure for significant systems-level energy efficiency improvement); combustion engines to reduce greenhouse gas (GHG) emissions; and technology deployment and integration at the local and state level. In coordination with the other offices across the Office of Energy Efficiency and Renewable Energy (EERE) and the U.S. Department of Energy (DOE), the Vehicle Technologies Office advances technologies that assure affordable, reliable mobility solutions for people and goods across all economic and social groups; enable and support competitiveness for industry and the economy/workforce; and address local air quality and use of water, land, and domestic resources.

The VTO Battery R&D subprogram supports the decarbonization of transportation across all modes, serves to increase American advancement/manufacturing of battery technology, and creates good paying jobs with the free and fair chance to join a union and bargain collectively. The subprogram supports research with partners in academia, national laboratories, and industry covered under the Energy Storage Grand Challenge key priority and distinct crosscuts. The Energy Storage Grand Challenge encompasses R&D across energy storage including the discovery of alternative lithium battery materials, processing for raw materials, development of advanced battery cells, discovery of innovative cell manufacturing techniques, and battery recycling. The Critical Minerals crosscut aims to reduce or eliminate cobalt and nickel in lithium battery cathode materials, develop substitutes for graphite such as silicon composite anodes and lithium metal anodes, and develop advanced recycling and processing through scale up of bench-scale recycling processes and innovative separation processes seedlings. The Advanced Manufacturing crosscut is focused on coordination with the Advanced Manufacturing Office for joint projects scaling up solid state battery materials and lithium metal electrode processing technologies addressing critical materials for batteries.

The Battery R&D activity supports early-stage R&D of high-energy and high-power battery materials, cells, and battery development that can enable industry to significantly reduce the cost, weight, volume, and charge time of PEV batteries. This activity is organized into sub-activities: advanced battery materials research, advanced battery cell R&D, and battery recycling R&D. Advanced battery materials research is coordinated with the Critical Minerals Initiative and includes: early-stage research of new lithium-ion cathode, anode, and electrolyte materials (currently accounting for 50-70 percent of PEV battery cost) and the development of "beyond lithium-ion" technologies, such as lithium metal anodes, solid-state electrolytes, and sulfur-based cathodes, that have the potential to significantly reduce weight, volume, and cost by three times, with a target of $60/kWh. Advanced battery cell R&D includes: early-stage R&D of new battery cell technology that contains new materials and electrodes that can reduce the overall battery cost, weight, and volume while improving energy, life, safety, and fast charging; and high-fidelity battery performance, life, fast charging, and safety testing of innovative battery technologies including recycled material and cells. Battery recycling R&D includes the development of innovative battery materials recycling and reuse technologies, and the Lithium-Ion Battery Recycling Prize, both to assure sustainability and domestic supplies of key battery materials and minerals.

Project Feedback

In this merit review activity, each reviewer was asked to respond to a series of questions, involving multiple-choice responses, expository responses where text comments were requested, and numeric score responses (*on a scale of 1.0 to 4.0)*. In the pages that follow, the reviewer responses to each question for each project will be summarized: the multiple choice and numeric score questions will be presented in graph form for each project, and the expository text responses will be summarized in paragraph form for each question. A table presenting the average numeric score for each question for each project is presented below.

Table 2-1 – Project Feedback

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat028	Materials Benchmarking Activities for Cell Analysis, Modeling, and Prototyping (CAMP) Facility	Wenquan Lu (ANL)	2-11	2.88	3.00	3.13	3.13	**3.00**
bat030	Electrode Prototyping Activities in ANL's Cell Analysis, Modeling and Prototyping (CAMP) Facility	Andrew Jansen (ANL)	2-16	3.50	3.33	3.33	3.17	**3.35**
bat164	Thick, Low-Cost, High-Power Lithium-Ion Electrodes via Aqueous Processing	Jianlin Li (ORNL)	2-20	3.25	3.25	3.13	3.00	**3.20**
bat167	Process Development and Scale-Up of Advanced Active Battery Materials	Ozge Kahvecioglu (ANL)	2-25	3.50	3.75	3.75	3.42	**3.65**
bat168	Process Development and Scale-Up of Critical Battery Materials - Continuous Flow-Produced Materials	Krzysztof Pupek (ANL)	2-31	3.63	3.50	3.63	3.38	**3.53**
bat183	In Situ Spectroscopies of Processing Next-Generation Cathode Materials	Feng Wang (BNL)	2-34	3.75	3.88	3.63	3.63	**3.78**
bat232	High Energy Density Electrodes via Modifications to the Inactive Components and Processing Conditions	Vincent Battaglia (LBNL)	2-38	3.00	3.00	2.63	3.00	**2.95**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat240	High-Energy Anode Material Development for Lithium-Ion Batteries	Cary Hayner (Sinode Systems/ NanoGraf)	2-43	3.30	3.00	3.40	3.20	**3.15**
bat247	Fast-Charge and Low-Cost Lithium-Ion Batteries for Electric Vehicles	Herman Lopez (Zenlabs Energy, Inc./ Envia Systems)	2-47	3.40	3.40	3.40	3.50	**3.41**
bat269	An Integrated Flame-Spray Process for Low-Cost Production of Battery Materials	Chad Xing (University of Missouri)	2-51	3.00	2.67	3.17	2.67	**2.81**
bat293	A Closed-Loop Process for End-of-Life Electric Vehicle Lithium-Ion Batteries	Yan Wang (Worcester Polytechnic Institute)	2-55	3.13	3.38	3.25	3.50	**3.31**
bat315	Process R&D for Droplet-Produced Powdered Materials	Joe Libera (ANL)	2-59	3.38	3.25	3.00	3.25	**3.25**
bat355	Development of High-Performance Lithium-Ion Cell Technology for Electric Vehicle Applications	Madhuri Thakur (Farasis Energy)	2-64	3.25	3.13	3.38	3.00	**3.17**
bat356	Lithium-Ion Cell Manufacturing Using Directly Recycled Active Materials	Madhuri Thakur (Farasis Energy)	2-67	3.38	3.13	2.88	3.00	**3.14**
bat377	ReCell–Overview and Update	Jeffrey Spangen-berger (ANL)	2-70	3.25	3.25	3.50	3.33	**3.29**
bat382	ReCell–Modeling and Analysis for Recycling	Qaing Dai (ANL)	2-74	3.36	3.36	3.36	2.92	**3.30**
bat386	eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Overview and Progress Update	Venkat Srinivasan (ANL)	2-79	3.50	3.30	3.50	2.88	**3.32**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat402	Improving Battery Performance through Structure-Morphology Optimization	Venkat Srinivasan (ANL)	2-83	3.75	3.50	3.75	3.63	**3.61**
bat441	High-Performance Electrolyte for Lithium-Nickel-Manganese Oxide (LMNO)/Lithium-Titanate (LTO) Batteries	Jennifer Hoffman (Gotion)	2-87	3.30	2.70	3.20	3.00	**2.95**
bat442	Behind-the-Meter-Storage (BTMS)–Overview and Update	Anthony Burrell (NREL)	2-91	3.63	3.50	3.50	3.50	**3.53**
bat456	eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Anode Structures that Enhance Fast Charge	Andrew Jansen (ANL)	2-95	3.58	3.42	3.58	3.17	**3.45**
bat457	eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Methods for the Detection and Quantification of Lithium Plating	Johanna Nelson-Weker (SLAC)	2-100	3.58	3.58	3.50	3.60	**3.58**
bat459	eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Heat-Generation Concerns Associated with Extreme Fast Charging	Matthew Keyser (NREL)	2-104	3.58	3.42	3.33	3.10	**3.41**
bat461	eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Quantifying Heterogeneities/Degradation During Fast Charge	Andrew Colclasure (NREL)	2-108	3.25	3.00	3.38	3.00	**3.11**
bat462	eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Aging and the Role of Fast-Charge Protocol	Eric Dufek (INL)	2-111	3.58	3.25	3.58	3.42	**3.40**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat463	eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Effects of Extreme Fast Charging on Lithium-Ion Battery Cathode	Tanvir Tanim (INL)	2-115	3.50	3.25	3.75	2.50	**3.28**
bat464	ReCell–Direct Cathode Recycling: Material Separation and Preparation	Albert Lipson (ANL)	2-119	3.67	3.33	3.17	3.17	**3.38**
bat465	ReCell–Direct Cathode Recycling: Relithiation and Upcycling	Jack Vaughey (ANL)	2-121	3.25	3.50	3.33	3.08	**3.36**
bat467	ReCell–Battery Design for Recycling	Jianlin Li (ORNL)	2-126	3.14	2.86	2.71	2.71	**2.89**
bat470	Process R&D Using Supercritical Fluid Reactors	Youngho Shin (ANL)	2-132	3.40	3.40	3.40	2.90	**3.34**
bat472	Behind-the-Meter-Storage (BTMS)–Materials	Kyusung Park (NREL)	2-137	3.00	3.17	3.33	2.92	**3.11**
bat473	Behind-the-Meter-Storage (BTMS)–Analysis	Margaret Mann (NREL)	2-142	3.56	3.31	3.38	3.25	**3.38**
bat475	Towards Solventless Processing of Thick Electron-Beam (EB) Cured Lithium-Ion Battery Cathodes	David Wood (ORNL)	2-148	3.42	3.17	3.25	3.25	**3.25**
bat478	Development of Thin, Robust, Lithium-Impenetrable, High-Conductivity, Electrochemically Stable, Scalable, and Low-Cost Glassy Solid Electrolytes for Solid State Lithium Batteries	Steve Martin (Iowa State University of Science and Technology)	2-154	3.38	3.38	2.13	3.50	**3.23**
bat479	Composite Solid Ion Conductor with Engineered Lithium Interface	Kyler Carroll (Wildcat Discovery Technologies)	2-158	3.33	3.00	1.83	2.83	**2.92**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat480	Physical and Mechano-Electrochemical Phenomena of Thin Film Li-Ceramic Electrolyte Constructs	Jeff Sakamoto (University of Michigan)	2-163	3.63	3.63	3.38	3.50	**3.58**
bat481	Li Dendrite-Free Li7N2I-LiOH Solid Electrolytes for High Energy Lithium Batteries	Chunsheng Wang (University of Maryland, College Park)	2-167	3.38	3.50	3.38	3.25	**3.42**
bat482	Hot Pressing of Reinforced Lithium Nickel Manganese Cobalt Oxide (Li-NMC) All-Solid-State Batteries with Sulfide Glass Electrolyte	Thomas Yersak (General Motors, LLC)	2-171	3.50	3.42	3.00	3.08	**3.34**
bat483	Low Impedance Cathode/Electrolyte Interfaces for High Energy Density Solid-State Batteries	Eric Wachsman (University of Maryland, College Park)	2-176	3.38	3.50	3.75	3.50	**3.50**
bat484	Developing an In-Situ Formed Dynamic Protection Layer to Mitigate Lithium Interface Shifting: Preventing Dendrite Formation on Metallic Lithium Surface to Facilitate Long Cycle Life of Lithium Solid State Batteries	Deyang Qu (The University of Wisconsin-Milwaukee)	2-180	3.38	3.38	3.50	3.38	**3.39**
bat485	Molecular Ionic Composites: A New Class of Polymer Electrolytes to Enable All Solid-State and High Voltage Lithium Batteries	Louis Madsen (Virginia Polytechnic Institute and State University)	2-185	3.42	3.25	3.50	3.33	**3.33**
bat486	All Solid State Batteries Enabled by Multifunctional Electrolyte Materials	Pu Zhang (Solid Power, Inc)	2-190	3.33	3.50	2.83	3.33	**3.35**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat487	Developing Materials for High-Energy-Density Solid State Lithium-Sulfur Batteries	Donghai Wang (Penn State University Park)	2-194	3.40	3.40	2.80	3.40	**3.33**
bat488	Fundamental Understanding of Interfacial Phenomena in Solid State Batteries	Xingcheng Xiao (General Motors, LLC)	2-198	3.50	3.33	3.83	2.83	**3.38**
bat489	Multidimensional Diagnostics of the Interface Evolutions in Solid-State Lithium Batteries	Yan Yao (University of Houston)	2-202	3.64	3.71	3.71	3.50	**3.67**
bat490	First-Principals Modeling of Cluster-Based Solid Electrolytes	Puru Jena (Virginia Common-wealth University)	2-207	3.50	2.83	2.83	3.00	**3.02**
bat491	Predictive Engineering of Interfaces and Cathodes for High-Performance All Solid-State Lithium-Sulfur Batteries	Badri Narayanan (University of Louisville)	2-210	3.17	3.00	3.08	3.00	**3.05**
bat492	Machine Learning for Accelerated Life Prediction and Cell Design	Eric Dufek (INL)	2-215	3.50	3.50	3.67	3.50	**3.52**
bat493	WPI USABC LCFC Project	Yan Wang (WPI)	2-217	3.50	3.40	3.60	3.40	**3.45**
bat494	Microvast USABC LCFC Project	Wenjuan Mattis (Microvast)	2-221	3.67	3.67	3.50	3.67	**3.65**
bat495	AMO/VTO FOA Award Applied Materials	Ajey M. Joshi (Applied Materials)	2-224	3.50	3.40	3.50	3.30	**3.43**
bat496	Silicon Consortium Project: Advanced Characterization of Silicon Electrodes	Robert Kostecki (LBNL)	2-228	3.75	3.50	3.50	3.75	**3.59**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat497	Silicon Consortium Project: Electrochemistry of Silicon Electrodes	Christopher Johnson (ANL)	2-231	3.63	3.63	3.63	3.50	**3.61**
bat498	Silicon Consortium Project: Next-Gen Materials for Silicon Anodes	Nathan Neale (NREL)	2-234	3.63	3.25	3.63	3.25	**3.39**
bat499	Silicon Consortium Project: Mechanical Properties of Silicon Anodes	Katherine Harrison (SNL)	2-237	3.38	3.13	3.38	3.25	**3.23**
bat500	Silicon Consortium Project: Science of Manufacturing for Silicon Anodes	Gabe Veith (ORNL)	2-240	3.63	3.25	3.75	3.25	**3.41**
bat501	Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Silicon Anode	Kristin Persson (LBNL)	2-243	3.50	3.38	3.75	3.38	**3.45**
bat502	Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Si Anode (Si-HPC)	Andrew Colclasure (NREL)	2-246	3.75	3.63	3.88	3.75	**3.70**
bat503	Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Silicone Anode	Jean-Luc Fattebert (ORNL)	2-249	3.63	3.38	3.50	3.25	**3.44**
bat504	3D Printed, Low Tortuosity Garnet Framework for Beyond 500 Wh/kg Batteries	Eric Wachsman (University of Maryland)	2-252	3.63	3.38	3.13	3.50	**3.42**
bat505	Advanced Electrolyte Supporting 500 Wh/Kg Li-C/NMC Batteries	Chunsheng Wang (University of Maryland)	2-256	3.38	3.38	3.50	3.13	**3.36**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat506	Composite Cathode Architectures Made by Freeze-Casting for All Solid State Lithium Batteries	Marca Doeff (LBNL)	2-259	3.50	3.38	3.50		**3.43**
bat507	Controlled Interfacial Phenomena for Extended Battery Life	Perla Balbuena (Texas A&M)	2-263	3.33	3.33	3.33	3.00	**3.29**
bat508	Design, Processing, and Integration of Pouch-Format Cell for High-Energy Lithium-Sulfur Batteries	Mei Cai (General Motors, LLC)	2-266	3.25	3.25	3.17	3.08	**3.22**
bat510	Electrochemically Stable High Energy Density Lithium-Sulfur Batteries	Prashant Kumta (University of Pittsburgh)	2-270	3.25	3.25	3.13	3.25	**3.23**
bat511	High-Energy Solid-State Lithium Batteries with Organic Cathode Materials	Yan Yao (University of Houston)	2-274	3.50	3.25	3.50	3.17	**3.33**
bat512	Highly Loaded Sulfur Cathode, Coated Separator and Gel Electrolyte for High Rate Li-Sulfur	Yong Joo (Cornell University)	2-278	3.08	2.92	3.00	3.00	**2.98**
bat513	Multifunctional Li-ion Conducting Interfacial Materials for Lithium Metal Batteries	Donghai Wang (Penn State University)	2-282	3.63	3.63	3.38	3.38	**3.56**
bat518	Solvent-free and Non-sintered 500 Wh/kg All Solid State Battery	Mike Wixom (Navitas Advanced Solutions Group)	2-286	3.00	2.63	3.25	2.88	**2.83**
bat519	Synthesis, Screening, and Characterization of Novel Low Temperature Electrolyte for Lithium-Ion Batteries	Xiao-Qing Yang (LBNL)	2-289	3.17	3.00	3.17	3.00	**3.06**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat520	Fluorinated Solvent-Based Electrolytes for Low Temperature Lithium-Ion Batteries	Zhengcheng Zhang (ANL)	2-292	3.17	3.00	3.17	3.33	3.10
bat521	Ethylene Carbonate-Lean Electrolytes for Low-Temperature, Safe, Lithium-Ion Batteries	Bryan McCloskey (University of California, Berkeley)	2-295	3.33	3.33	3.33	3.50	3.35
bat522	Thin-film Lithium Metal Manufacture by Room Temperature Electrodeposition	Alirio Liscano (Albemarle)	2-299	3.13	2.88	3.00	2.88	2.95
Overall Average				3.41	3.29	3.32	3.22	3.32

Presentation Number: bat028
Presentation Title: Materials Benchmarking Activities for Cell Analysis, Modeling, and Prototyping (CAMP) Facility
Principal Investigator: Wenquan Lu (Argonne National Laboratory)

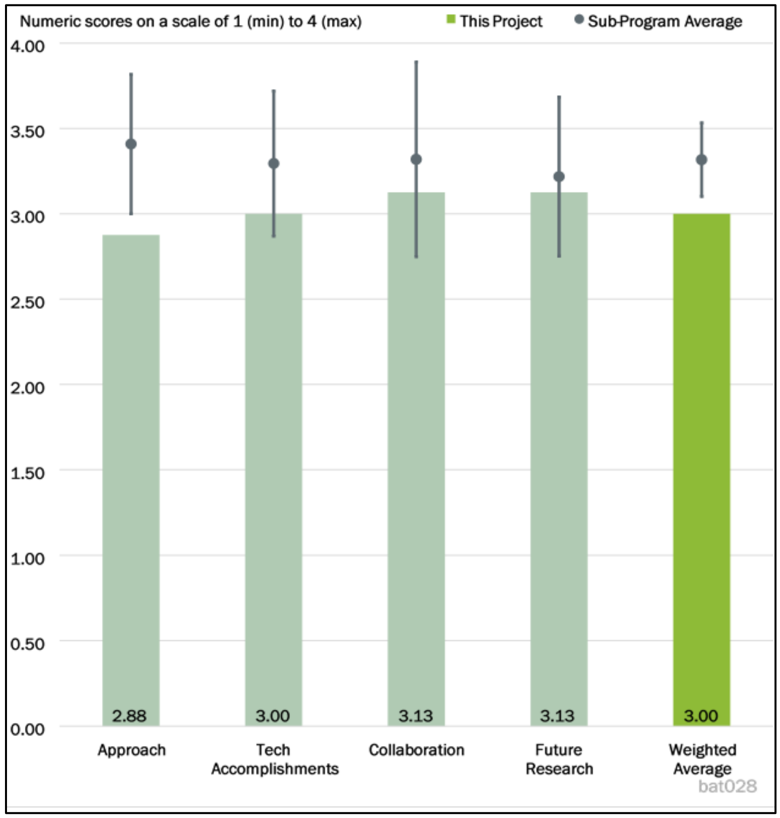


Figure 2-1 - Presentation Number: bat028 Presentation Title: Materials Benchmarking Activities for Cell Analysis, Modeling, and Prototyping (CAMP) Facility Principal Investigator: Wenquan Lu (Argonne National Laboratory)

Presenter

Wenquan Lu, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

Based on the slide deck, it was not clear to the reviewer what the benchmark is and what the selection protocol is for screening materials. It also appears that the new materials development was undertaken as part of this project. The work presented is very interesting and very encouraging and is covering a wide range of topics definitely supporting some of the objectives. The reviewer asked for the project team to please comment on cost reduction opportunities for each project undertaken.

Reviewer 2:

According to the reviewer, the project's approach is generally effective but could be improved with a little more focus on evaluating more relevant cathode and anode materials and developing processes for electrolytes. It does contribute to overcoming the barriers in the development of electric vehicle (EV) batteries that can meet DOE and United States Advanced Battery Consortium (USABC) goals both in cost and performance by performing the evaluation of high energy active martials. This is part of a larger activity (the reviewer was not sure why this should be a separate project) related to the materials benchmarking activities for Cell Analysis, Modeling, and Prototyping (CAMP). It is no doubt important to have standardization in the materials evaluation, especially because of the wide category of materials being pursued by DOE, which are continuing to evolve.

The reviewer identified two weaknesses. Firstly, and despite the on-going work on the development of solid polymer electrolyte membrane and the assessment of holey graphene, this project does not seem to be well connected with the material development in other (DOE) laboratories. Secondly, benchmarking needs to be done on the materials currently used in or rapidly emerging from industry, either in liquid electrolyte or solid electrolyte (SE) systems, but the project does not seem to have established any such connections. Getting access to such materials may be challenging, but efforts should be made in that direction.

Reviewer 3:

The question the reviewer had relates to the focus of the work. It was clear to the reviewer that benchmarking of new battery materials is a critical task in terms of sorting out whether new materials have any favorable comparison (or not) to existing established materials. To that end, the benchmarking aspect of the project is certainly important. What was not clear to the reviewer is whether the project goal is to develop new materials or to evaluate proposed materials from developers to provide feedback as to commercial relevance. There seems to be a mix of activities along this front, and the reviewer assumed that this issue has been discussed; however, the reviewer found the charter of the project a little confusing. That is not to say that the work is not well planned or executed, the reviewer was just unsure whether the goals are sufficiently clear.

Reviewer 4:

The reviewer commended the multiple methods developed to produce both cast and stand-alone separator films. However, it would have been good to understand more about the degree of challenges that were overcome; for example, ran X experiments with Y outcomes and required Z cycles of data to achieve results. In addition, it would be good to discuss next steps, or challenges, even if out of scope for the current effort.

For solid electrolyte approaches, it would have been good to map out properties in terms of thickness and operating temperature. In addition, the reviewer asked the project team to please highlight the technical gaps in performance that might limit or enable further development or scale-up.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer asserted that good progress has been made: developing methods for standalone and direct casting solid-state electrolyte (SSE) thin films on a lithium (Li) anode by incorporating solid electrolytes, which showed good performance in cells with lithium iron phosphate (LFP) cathode; evaluating silicon that is made from halloysite preserves high specific capacity; and evaluating binder and solvent-free nickel manganese cobalt oxide (NMC) cathodes holey graphene, which showed decent performance at high loadings. The results with a solid electrolyte membrane are particularly interesting, though details are missing on LFP cathode (if the same solid electrolyte or some other ionic conductor is dispersed in the composite cathode).

This reviewer also identified one weakness—among the three activities, the first one has greater relevance to the project, but the latter two tasks do not have as much relevance and the results are not noteworthy. This underlines the need for better coordination for bringing relevant tasks into this project.

Reviewer 2:

All experimental work is of high quality and results are very encouraging, according to the reviewer. Clear performance/benchmarking targets for each material/component would be helpful. in the slide deck as the performance indicators are only shown at a cell level.

The reviewer inquired about the form of silicon (Si) with respect to the 1,800 milliampere-hours per gram (mAh/g) specific capacity on Slide 13.

Reviewer 3:

The milestones for the time period were stated as developing coating methods to produce solid-state ceramic separators. It was not clear to the reviewer whether any commercial solid-state ceramic systems were benchmarked in order to establish the state of the art. Several activities were presented that were not part of milestones for this time period.

Reviewer 4:

Although the information and progress demonstrated is impressive, the reviewer was disappointed that the stated goal to "benchmark state of the art material from partners" seemed disjointed from the progress and data achieved. However, this was clearly not an issue with the project owner(s), but more a symptom of not having access to those materials. In light of this, maybe the whole project goals should be reevaluated. For example, it was difficult for the reviewer to connect the overall project objectives with the year's accomplishments and how they link to the USABC objectives. The reviewer suggested that, in a future request to properly review progress, a section be added to the project on how the milestones were chosen and how they tie to the overall project goals.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said that technical collaboration is commendable and shows in the great use of the characterization techniques.

Reviewer 2:

The reviewer mentioned several on-going collaborations: U.S. Department of Energy (DOE) laboratories (Argonne National Laboratory [ANL], Brookhaven National Laboratory [BNL], Oak Ridge National Laboratory [ORNL], and Pacific Northwest National Laboratory [PNNL]), National Aeronautics and Space Administration (NASA), universities (Indiana University – Purdue University Indianapolis [IUPUI], University of Missouri, University of Arkansas, The George Washington University, Western Michigan University, Brigham Young University, and University of Louisville), and industrial partners (Applied Minerals, Jolt Energy Storage Technologies, Koura, Lubrizol, NEI, Osaka Titanium Corp., OSiAlC , Paraclete Energy, Phillips 66, Superior Graphite Co., Targray, and Toda Kogyo).

The reviewer brought up two weaknesses: (1) it is not clear what the specific activities and materials are in these collaborations as it would be helpful if the activity is mentioned for each of the collaborations and (2) collaboration with any battery company manufacturer would be beneficial.

Reviewer 3:

As the PI stated, it would have been helpful to the reviewer to find more state-of-the-art partners who could take advantage of the project and help advance the science. The reviewer wanted to know if there should be more effort made to market this project or find other collaboration models that can bring in partners, especially those from industry.

Reviewer 4:

No issues were noted by this reviewer.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer mentioned that the proposed future work is effectively and logically planned by continuing the development of solid-state electrolyte (SSE) effort, especially focusing on the fabrication scalability of oxide and sulfide SSE (lithium lanthanum zirconium oxide [LLZO], Li_6PS_5Cl) and integration into prototype cells will be quite useful and relevant. Additionally, there are plans to acquire and characterize high-energy anode and cathode materials from domestic vendors, including thermal properties. Overall, the future plans are to continue to work closely with research institutions and industrial suppliers to enable the lithium-ion battery (LIB) technology for EV applications.

Reviewer 2:

The reviewer thought that the future effort outlined makes sense in the context of the barriers to obtaining new, state-of-the-art materials.

Reviewer 3:

The future goals are broad but relevant, according to the reviewer.

Reviewer 4:

As the team has suggested, it is important to balance research and validation activities. The reviewer stated that the work on solid electrolytes is outlined very well.

The comment on the ability to source advanced materials is valid, and the project team might consider creating a model that will allow industry to collaborate with the national laboratories while protecting the background and resulting intellectual property (IP).

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

According to the reviewer, the project supports the overall DOE objectives by validating the rapidly emerging electrode and electrolyte materials being marketed and reported to improve lithium-ion batteries. A centralized facility is required for a consistent and correct assessment of these materials, either for material development or material benchmarking, which this project is intended to do. This project has therefore a dual role of interacting with universities and national laboratories for material development and industry for material assessment and benchmarking. Overall, this is quite relevant to the DOE VTO battery programs.

Reviewer 2:

The reviewer remarked that third-party validation of the new materials and their compatibility with other cell components is critical for the industry as a whole. Developing processes to support the scale-up of the new materials should be the CAMP facility's focus.

Reviewer 3:

Material benchmarking of advanced materials in battery systems is critically important. The reviewer said that focusing on the scope of the project should continue.

Reviewer 4:

The reviewer responded affirmatively and said that the projects described encompass potentially low-cost methods to form solid electrolytes, to find straightforward techniques to generate Si nanomaterials, and to find methods to form binder and solvent-free cathode electrode; these are important and relevant. However, the reviewer would like to have more analysis presented. For example, the reviewer wanted to know how much cost is saved versus how much is potentially added as part of the cathode project, whether that makes it a relevant project, and what its importance is.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

According to the reviewer, resources are commensurate with the scope of the project and adequate to achieve the stated milestones.

Reviewer 2:

Given that the objectives are on track to be achieved, or have already been achieved, the reviewer asserted that it would be a good assumption that the goals are properly resourced.

Reviewer 3:

The reviewer found the resources to be sufficient. However, there might need to be some legal or project management support to improve access to the new materials.

Reviewer 4:

This reviewer noted no issues.

Presentation Number: bat030
Presentation Title: Electrode Prototyping Activities in ANL's Cell Analysis, Modeling and Prototyping (CAMP) Facility
Principal Investigator: Andrew Jansen (Argonne National Laboratory)

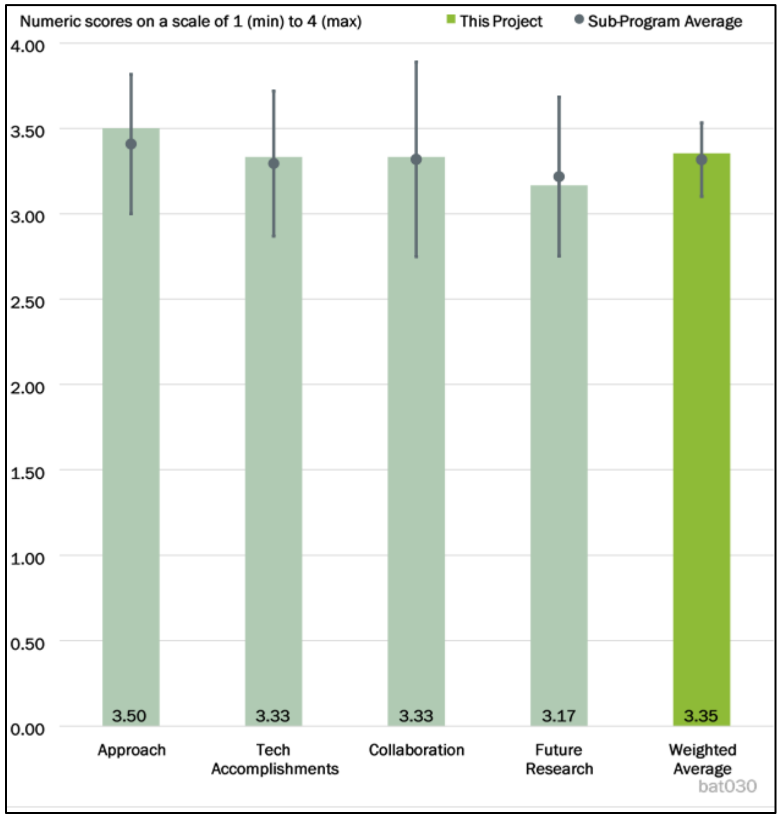


Figure 2-2 - Presentation Number: bat030 Presentation Title: Electrode Prototyping Activities in ANL's Cell Analysis, Modeling and Prototyping (CAMP) Facility Principal Investigator: Andrew Jansen (Argonne National Laboratory)

Presenter

Andrew Jansen, Argonne National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 67% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 33% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

According to the reviewer, this is a superb project for the development of new technologies for electrodes. It is a great service to other labs and universities. This project addresses very carefully the major barrier, which is to increase the energy density that is very limited in present commercial batteries as well as focus on using materials that guaranteed safety, good cost, and long cycle life. A great advantage of this project is the testing of small-scale electrodes before going to large and commercial scale.

Reviewer 2:

The reviewer asserted that the project aims to scale up a material evaluation from bench-top to pre-pilot or pilot level. The PI has demonstrated that the project’s capability of scale-up evaluation for the materials is building up. The project is well designed and feasible; for example, a multi-functional coater has been designed and optimized and therefore materials of different kinds can be tried at pilot level.

Reviewer 3:

The reviewer observed that the proposal is generally effective but needs a little more focus on evaluating more relevant and newer cathode and anode materials and electrolytes. This is a fairly big project and is the only DOE project that provides independent validation within DOE for new materials being developed under VTO projects. It helps to overcome the barriers to the development of advanced EV batteries by assisting in the development of new materials that will provide performance enhancement and/or reduced cost. It is crucial to have standardization in the assessment of the materials, particularly in bigger pouch cells (instead of coin cells), especially because of the wide category of materials continuing to evolve under the VTO projects.

The reviewer mentioned three weaknesses: (1) there is little material assessment being done on "Beyond Li-ion battery" technologies, i.e., either Si-NMC or Li-sulfur (S) technologies. Even for Li-ion technologies, this project has not really caught up with the new materials (high Ni), high-voltage electrolyte, etc. (2) The PIs should be encouraged (or even mandated by DOE) to utilize the CAMP faciality as a pathway toward scale-up and commercialization of their technologies. (3) Benchmarking needs to be done on the materials currently used in or rapidly emerging from industry, but the project does not seem to have established any such connections yet. Getting access to such materials may be challenging, but efforts should be made in that direction.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer noted that multiple instruments, e.g., multi-functional coater, were set up and tested. The capability of manufacturing a large electrode web was demonstrated. The facility has served many customers.

Reviewer 2:

The reviewer stated that progress goes as planned with some constraints due to coronavirus disease 2019 (COVID-19). Major breakthroughs are coming together with the BAT028 project. The scheduled milestones so far have been concluded successfully, and those in progress are providing the expected results.

Perhaps the PIs should report more extensive tables comparing the coatings and cathode materials. These comparisons should include such factors as safety, cycling life, and cost as well the other, already reported factors as cobalt mass per energy and energy per mass (g-density). For both cathodes and coatings materials, the reviewers may have a better idea of the big picture behind these prospective materials. Also, except for the baseline anode (graphite) and silicon monoxide reports in virtual conferences, all the effort in anodes has been limited to the baseline (graphite).

Reviewer 3:

The reviewer found that good progress has been made in supporting several DOE projects by providing advanced prototype electrodes (baseline and novel materials), which is one of the main objectives of this project. Likewise, the process for coating hybrid ceramic polymer composites and electrode ceramic structures using the roll-to-roll (R2R) reverse comma coater has been optimized (also listed in another project, which may be a sub to this). A multi-functional coater is being installed that may benefit many projects. Finally, radiography and energy dispersive X-ray diffraction are being explored to probe electrode heterogeneity in thick electrodes. Overall, the progress is fair and generally effective and helps in alleviating the problems of variability in electrode assessment and problems related to coating polymer electrolyte and solid electrolyte films on a Li anode.

Regarding weaknesses, the reviewer commented that two of the project activities—supplying electrodes to the other PIs and installing a new multi-functional coater—have greater relevance to the project and are beneficial to other on-going projects. However, the project has yet to address the more current materials for Li-ion batteries and also new materials for beyond Li-ion technologies. This underlies the need for better coordination with DOE for bringing relevant tasks into this project.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer stated that this project has extraordinary collaborations, providing electrodes and cells to several first-tier universities, to leading industrial companies in the battery business, and to several of the major national laboratories.

Reviewer 2:

The reviewer remarked that there are several on-going collaborations listed here, within and outside DOE, several universities, and industrial partners. The majority of these collaborations over the past several years are related to the CAMP Facility providing electrodes and cells.

According to the reviewer, one weakness in the project is that it is probably useful to provide further description of the materials and cells supplied to the collaborators to assess the scope and benefits of such collaborations.

Reviewer 3:

The reviewer indicated that the CAMP Facility has provided electrode and cells to universities, national laboratories, and industry. The reviewer suggested that the PI should consider reaching out to collaborate with either academics or industry to gain knowledge of scale-up processing of materials with different properties in addition to different chemistries.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer found that the proposed future work is effectively and logically planned: demonstrate the functionality of new multi-functional coated with hybrid ceramic polymer composite coatings; explore new electrode formulations with reduced binder; and expand the electrode library by adding new materials of various NMC formulations such as high Ni, NMC, and SiO_x etc. Overall, the future plans are to continue to work closely with research institutions and industrial suppliers to enable the LIB technology for EV applications.

Reviewer 2:

All seemed very well planned to the reviewer, who commented that the development of better anodes should have a stronger emphasis in this project, such that development of electrolytes and cathodes are in full balance with the development of anodes.

Reviewer 3:

The reviewer remarked that the proposed research in the next budget period is to demonstrate hybrid ceramic-polymer coating capability for the coater and enhance the electrode library. The research aligns well with the objective. However, the reviewer suggested that the PI enhance the diagnosis so the impact of properties on the processability can be better understood.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer remarked that the project supports the overall DOE objectives by validating the rapidly emerging electrode and electrolyte materials being marketed and reported to improve lithium-ion batteries. A centralized facility is required for an independent verification and validation of these materials, either for material development or materials benchmarking, which this project is intended to do. This will be essential for subsequent implementation (and commercialization) of these materials in EV cells. This project also provides good baseline electrodes (in the electrode library) to other battery projects as a way of standardization. This project has a dual role of interacting with other DOE-VTO PIs at universities and national laboratories for material development and industry for material assessment and benchmarking. Overall, this is quite relevant to the DOE VTO battery programs.

Reviewer 2:

The reviewer agreed that the project supports the DOE objectives. The project aims to facilitate evaluation of new electrode materials from tens of grams scale to kilogram scale. The CAMP facility would assist the material development and scale-up investigations.

Reviewer 3:

This project is fully relevant to all aspects of DOE objectives, according to the reviewer.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer stated that resources are commensurate (even slightly higher) with the scope of the project and adequate to achieve the stated milestones.

Reviewer 2:

The reviewer commented that the resources are really more than sufficient, except that some new sophisticated measurement equipment may be needed.

Reviewer 3:

The reviewer remarked that ANL has excessive resources in engineering design and advanced diagnosis.

Presentation Number: bat164
Presentation Title: Thick, Low-Cost, High-Power Lithium-Ion Electrodes via Aqueous Processing
Principal Investigator: Jianlin Li (Oak Ridge National Laboratory)

Presenter

Jianlin Li, Oak Ridge National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

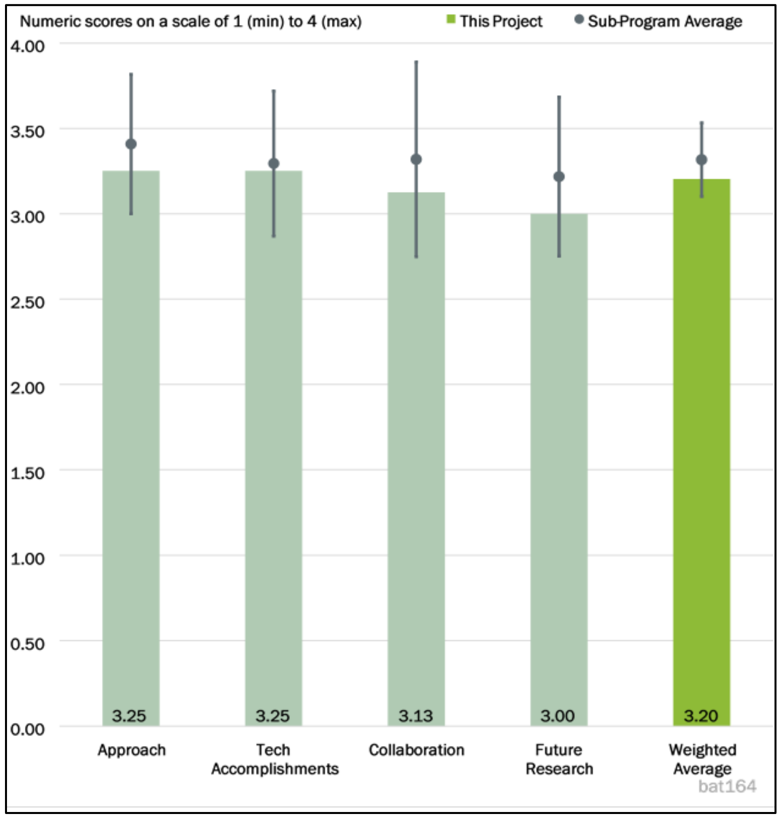


Figure 2-3 - Presentation Number: bat164 Presentation Title: Thick, Low-Cost, High-Power Lithium-Ion Electrodes via Aqueous Processing Principal Investigator: Jianlin Li (Oak Ridge National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer commented that there is a well-defined approach toward achieving project milestones and direct relevance to solving barriers addressed in the project. The technical barrier of achieving high loading, crack-free electrodes has been addressed with double pass and mixed particle size coating techniques. The path to improving high resistance on aqueous-processed nickel manganese aluminum oxide (NCA) has been identified. A freeze tape cast, hybrid electrode structure for improving rate capability has been developed.

Reviewer 2:

The reviewer found that the project is generally effective and contributes to overcoming barriers in the development of crack-free dense cathodes using low-cost and environmentally compatible aqueous slurries for EV batteries that can meet both DOE and USABC cost goal. The main objective of improving cell energy and power density and reducing battery pack cost by manufacturing thick electrodes with tailored electrode architecture is consistent with the VTO program goals. Cathode fabrication is a crucial step in defining both the performance and cost, and aqueous processing methods for high-energy cathodes (NMC 811) are superior to conventional N-methyl-2-pyrrolidone (NMP)--based method for cost and environmental reasons.

There are no serious weaknesses here, according to the reviewer. However, it would be interesting to see how this aqueous processing method compares with recently emerged “dry fabrication” methods. Apart from cost, the reviewer asked whether there had been a cost comparison among these three methods (NMP, aqueous, and dry). The development of a composite cathode with co-sintered solid electrolyte, though interesting, is not relevant to the theme of the project for improving Li-ion batteries, but only to solid-state batteries, which are now part of the future study. The reviewer inquired about how the co-sintered composite cathode compares against the composite cathode obtained by mechanically mixing of cathode and well characterized solid electrolyte powder and whether it is possible to work with lower proportions of solid electrolytes in co-sintered cathodes. Finally, it would be more appropriate to extend this aqueous processing to the "Beyond Li-ion" technologies (Si-NMC and Li-S, which will possibly achieve technology maturation sooner than solid-state batteries).

Reviewer 3:

The reviewer asserted that the project aims to develop thick electrode with tailored electrode architectures. The water-based cathode process was explored, and a freeze tape casting technique was investigated to construct layer structures. Fundamental studies, including modeling, were conducted to understand mass transport in a thick electrode.

The reviewer opined that there were two issues the PI should have addressed: (1) whether NMC811 was stable in the aqueous condition and (2) the cost and impact of line speed of the freeze tape casting.

Reviewer 4:

The reviewer noted that the project is focused on the production of thick (6-8 mAh/square centimeter [cm^{2}]) Li-ion electrodes for EVs at $80/kilowatt-hour (kWh) by 2022 and for architectures for hybrid and EV battery systems. Another goal is to achieve a discharge cycling of 1,000 for EVs by 2022. This is done using an aqueous processing to Ni-rich layered oxides, including the demonstration of a solid-state battery (SSB) of at least 350 watt-hour per kilogram (Wh/kg). The PI reported a delay of 3 months for these goals due to COVID-19. Still, the PI reported major problems for which a technical approach and strategy has been planned. Perhaps the few alternatives on fabrication based on transition metal oxides as cathode electrodes are not enough to reach ambitious goals.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

Given the circumstances (COVID-19), the reviewer believed that the group has made a strong effort to keep up in the best way possible with the scheduled research.

Reviewer 2:

The reviewer saw good progress having been made toward the stated goals to date. Some delays due to restricted lab access due to COVID-19 delayed a milestone. Thick cathode processing with double pass coating to improve rate performance was shown, and cyclability of these electrodes needs to be demonstrated. Cost reduction efforts using aqueous, thick electrode processing are clearly defined. Progress toward other key metrics of greater than 250 Wh/kg and 1,000-cycle milestones were not clearly articulated. It was unclear to the reviewer how the solid-state battery effort is related to the overall high-level goals of cost reduction, thick electrodes, and overall project goals of low-cost manufacturing.

Reviewer 3:

According to the reviewer, good progress has been made in developing aqueous processing for new cathode materials including NCA and the high-Ni NMC (811) and demonstrating rate and cycling performance in thick cathodes with high areal capacity (6-8 mAh/cm^2). The high-rate performance (greater than a C-rate (C) of 1C) seems to be further improved with architectures having small particles combined with large particles, either randomly mixed or arranged in a layered structure. The reviewer inquired as to whether this is entirely due to the increased surface area or due to any enhanced electrolyte penetration and/or wetting with the "layered" arrangement of smaller particles over larger particles. An interesting method and analysis have been developed to probe electrolyte wettability in thick electrodes. The reviewer asked if this can be extended to the discharge condition at high rates to assess electrolyte permeability into the porous cathode. Finally, the possibility of co-sintering solid electrolyte together with the cathode material for intimate mixing has been demonstrated. It would be interesting, however, to verify if this provides any enhanced ion conduction to the cathode compared to conventional (mechanical) mixing of cathode and solid electrolyte.

Reviewer 4:

The reviewer stated that the project team made a thick NMC811 cathode using the aqueous process. Improved rate performance of the thick electrode was demonstrated in a two-layer structure electrode. The capability of freeze tape casting was also demonstrated. The reviewer suggested that the PI should be more focused on the stability of the cathode material in an aqueous environment and optimization of both electron and ion transfer.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer said that there are several useful and on-going collaborations stated here with the DOE laboratories (ANL, Sandia National Laboratories [SNL], and Idaho National Laboratory [INL]), academia (Karlsruhe Institute of Technology [KIT], State University of New York at Binghamton [SUNY Binghamton], University of Picardy Jules Verne, and University of Arkansas), and battery manufacturers. This project requires good interactions to develop processing methods for the relevant materials.

The reviewer noted two weaknesses. Firstly, it was unclear what the specific activities and/or materials are in these collaborations. It would be helpful if the activity is mentioned for each of the collaborations. Secondly, collaboration with any battery company manufacturer to demonstrate the aqueous electrode fabrication methodology for dense cathodes in a production environment (pilot plant) would be beneficial and will facilitate commercialization.

Reviewer 2:

The reviewer remarked that the cross-functional project team was good and coordination across partners was impressive. There is a good cross section of university, national laboratories, and industry partners in the project. The reviewer stated that an overall summary of how these different partnerships are working in concert toward solving the key barriers identified in the project would be helpful.

Reviewer 3:

It seemed to the reviewer that there was collaborative research at the PI's institution, but it was not clear how outside collaborators contributed to the project.

Reviewer 4:

The reviewer commented that this project has very good active collaborations with Binghamton University, but much less frequently with the University of Picardy (France) and others, such as ANL, JSR, and Navitas.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The proposed future studies focusing on the fabrication of composite NMC cathode with 3 mAh/cm^2 for solid-state batteries and polymer electrolytes and to optimize the freeze tape casting method for the NMC cathode for solid state batteries looks good no doubt, but this is a long-term solution. For the immediate needs, the reviewer said that it would be better if the aqueous processing methodology were extended to the "Beyond Li-ion" technologies (Si-NMC and Li-S), which may be able to attain technical readiness and maturity earlier than solid-state batteries.

Reviewer 2:

Future work looked to the reviewer to be primarily focused on solid-state batteries. It was unclear how the thick electrode work and the solid-state battery work are connected. The project milestones and objectives need to be re-written if this is the case.

Reviewer 3:

The PI proposed to continue and extend the process development into cathode and solid-state electrolyte and polymer electrolyte. The project team will take the advantage of freeze tape casting and apply it to a making solid-state battery. The reviewer encouraged the project team to take into consideration the significant difference of solid-state electrolyte processing.

Reviewer 4:

The proposed research is very challenging, and the group is working hard on it; however, the reviewer asserted that an effort should be done to correct toward other technologies.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer opined that the project supports the overall DOE objectives by developing low-cost and environmentally friendly fabrication methods for dense and high areal capacity electrodes for lithium-ion cells. The conventional method is expensive and involves environmentally incompatible solvents (NMP). Overall, this is quite relevant to the DOE VTO battery program.

Reviewer 2:

Low-cost manufacturing of batteries by using aqueous processing and enabling thick electrodes for both cost and energy density reasons is directly related to the DOE objectives, according to the reviewer.

Reviewer 3:

The reviewer commented that making high energy density, e.g., thick, electrodes and exploring low-cost options for electrode making are relevant to the overall DOE objectives.

Reviewer 4:

The reviewer affirmed that, in general, this project supports the overall DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted that resources are commensurate with the scope of the project and adequate to achieve the stated milestones.

Reviewer 2:

Except for additional highly sophisticated equipment, the reviewer said that the resources are enough.

Reviewer 3:

Resource breakdown was not provided. The reviewer assumed resources are sufficient based on project milestones tracking.

Reviewer 4:

The reviewer said that Oak Ridge National Laboratory has more than sufficient resources to conduct the proposed research.

Presentation Number: bat167
Presentation Title: Process Development and Scale-Up of Advanced Active Battery Materials
Principal Investigator: Ozge Kahvecioglu (Argonne National Laboratory)

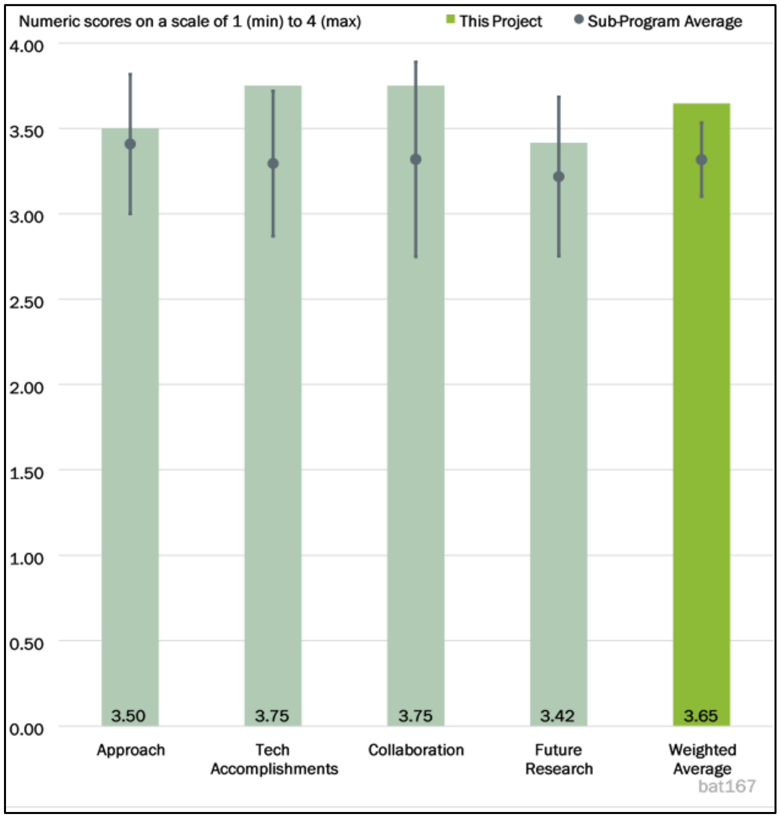


Figure 2-4 - Presentation Number: bat167 Presentation Title: Process Development and Scale-Up of Advanced Active Battery Materials Principal Investigator: Ozge Kahvecioglu (Argonne National Laboratory)

Presenter

Ozge Kahvecioglu, Argonne National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

Overall, this is a novel approach to synthesize materials at a scale that bridges the needs of academia and industry-scale research and development (R&D). The project team has made strong progress in a short amount of time. The reviewer thought that the approach and strategy are strong.

Reviewer 2:

The reviewer commented that the project has established a range of synthetic capabilities to support a variety of requests for high--quality cathode material. The establishment of Taylor Vortex Reactor (TVR) coprecipitation synthesis at 10-liter (L)-scale is important. The project appears to have established a reasonable feedback loop between customers and the project so that the necessary capabilities are in place to allow the project to address customers' needs. There may be room for new chemistries to be introduced (e.g., different coprecipitation chemistry or the introduction of alloying that was mentioned in the presentation) to be better prepared to provide customer requests beyond the lithium-nickel dioxide ($LiNiO_2$) (LNO) materials being provided now. But, given the mission to provide high quality cathode material in prototyping quantities to the battery community at large, the approach is excellent, the team is in communication with the community, and the team appears ready to be able to address most requests.

Reviewer 3:

The reviewer asserted that this project utilizes the mid-scale production facility at ANL to synthesize large quantities of non-commercial LNO-based cathode materials. The team has been successful in supporting the broad DOE battery research community by supplying cathode materials that are not commercially available to many projects for large-format cell testing, which fills a gap between bench-scale and high-volume production. It also demonstrates that the Taylor Vortex Reactor could manufacture cathodes with improved properties over the traditional co-precipitation method, which holds promise as a cost-effective, scalable process.

Reviewer 4:

The reviewer said that the ability to provide different formulations of high-Ni cathodes in a systematic way in meaningful volumes is important. Extensive use of the resources available was demonstrated by looking at combinations of formulations and processing conditions to produce a variety of results. However, one of the key objectives was to produce enough quantities to be meaningful to associated research projects. It would have been good to show some metrics of what the goals were and how much of this was in fact achieved.

Reviewer 5:

The goals were clearly defined, but the reviewer stated that the technical approach was not. For example, Slide 5 discusses the approach, but no technical details are given as to what the synthesis approach is and why it is a cost-effective scalable process, which is one of the key goals. There should be a slide or brief text in the presentation regarding the Taylor Vortex Reactor and what this approach is (yes, in the oral presentation this was described a bit), but more importantly why this is a scalable process that is cost effective. The reviewer wanted to know where the cost comparisons are that define this approach as novel and cost effective and scalable versus today's state of the art. This needs to be laid out in the beginning to justify this work. Otherwise, it still has value in supplying partners with hard-to-obtain compositions.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer asserted that the project team has made significant progress in several fronts. It successfully scaled up the production of NMC precursors with high-Ni contents using the TVR method and explored the effects of processing conditions (power of hydrogen [pH], calcination temperature, and oxygen partial pressure) on the electrode performance. It compares the morphology and performance of NMC precursors synthesized by the TVR versus the co-precipitation method and reveals that the former produces more spherical particles with a broader particle size distribution and improved rate capability. The team also supplies cathode materials to many collaborators and facilitates a wide range of research studies from new electrode design to characterization and battery recycling.

Reviewer 2:

It was clear to the reviewer that the PI has been successfully fabricating materials to supply DOE partners. The reviewer would have liked to see more benchmark results of materials made by this process versus commercially obtained materials. The reviewer realized that one of the purposes of this project is to supply novel hard-to-find materials, but maybe just a side effort to use this process. Also, there should be some discussion and data about particle-size distribution and how this is controlled and optimized using this process. Some data regarding scaling and cost effectiveness should be shown. However, it seems the PI has made really excellent progress in the relatively short time the project has been active and hit a large number of the milestones.

Reviewer 3:

Overall, for the short time duration of the project (October 2020 start date), the results are both interesting and promising for the battery community. The reviewer was Interested to see longer term results with LNO and nickel cobalt manganese oxide (NCM) and the further box furnace optimizations. For the box furnace optimizations, it is not clear what the PI has planned, but perhaps some basic thermal or gas flow models can give insight if experimental iterations hit roadblocks. It would also be helpful to know time scales for synthesis and estimated D10, D50, and D90 numbers for all materials created. While the d50 is the nominal metric used, the full PSA is also helpful to know for the materials. The PSA was given on Slide 7, but not on all the slides.

Reviewer 4:

The project overall appeared to the reviewer to be on track with both its process and chemistry development goals as well as its related mission to provide high-quality materials to various customers. The project is responsible for developing new capabilities, presumably to stay at or near the state of the art. It was not exactly clear what the near-term targets were for capability development, so it is hard to judge how well the project team is doing against expectations. But, some of the presentation touched on materials beyond LNO and chemistries such as alloying during the coprecipitation stage to avoid a costly alloying step later, so the project appears to be moving forward reasonably well with capability development. The progress on meeting customers' requests looks excellent in terms of material delivered; it is clear that many customers, especially in VTO-funded projects, are getting high-quality material in a large enough quantity to complete their research. What was not clear was the timeline for fulfilling a request: that is, the time on average from the first discussion of the need to the delivery of a kilogram of high-quality cathode material. Perhaps the project could establish a measure for the time between request and delivery and report that measure in the future to help understand if this aspect of the project is meeting its performance expectations.

Reviewer 5:

Given the short duration of the project to date and the difficulties associated with completing lab-based work in the COVID-19 environment, the reviewer found that the progress demonstrated was outstanding. It would be, however, helpful in the future for each of the sub-projects to better define the goals of the optimization projects. For example, parameters such as primary and secondary particle size, key surface and bulk characteristics, etc. It would also be helpful to show if those initial goals were adjusted based on feedback from partners. In addition, since one of the key objectives is to deliver sufficient amounts of specific materials, it would be helpful to set those goals ahead of time and measure their progress (as opposed to "scaled up to 10 L TVR"). In addition, the reviewer asked if there should be metrics on reproducibility, as that is a key component of the scale-up process.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The project team collaborates extensively with the subgroups in the Deep-Dive into Next-Generation Cathode Materials effort and supplies many high-Ni NMC precursors to different projects. It also supports other VTO-funded projects and university research. Overall, the reviewer called the collaborative element of the project outstanding.

Reviewer 2:

This reviewer referenced Slides 4 and 17 and the oral presentation, which clearly described a number of material deliverables to the overall team. Clearly there seemed to the reviewer to be great communication among the local team and the larger DOE community. Many samples have been fabricated, and the PI and team seem to be very active and proactive with communication.

Reviewer 3:

According to the reviewer, the results of the collaboration efforts are clearly demonstrated. What would be helpful is if feedback (if any) were included in the effort on next steps on how to improve results from a material perspective.

Reviewer 4:

The reviewer had no doubt from the presentation that the project is working very closely and in good collaboration with a large number of VTO-funded projects and has been integral to the success of those projects. Collaborations with non-VTO funded projects, such as start-up companies (there seemed to be only one, Volexion), was far more limited. Perhaps this simply reflects a low demand from outside the VTO-funded community, but if this is important, then some progress needs to be made in developing such collaborations with industry and academia. Nevertheless, the level of collaboration and coordination within the VTO-funded community is outstanding and a clear strength of the project.

Reviewer 5:

Given the project is trying to fill a niche for industry or companies that are not able to take on the financial risk of process development and scale-up of multiple new materials, the reviewer thought that it is prudent to have another company or industry research lab involved as an additional collaborator or at least advisor of general material needs and requirements.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The proposed future research would optimize the calcination processes, scale up the production of new cathode chemistries, and continue to provide commercially unavailable cathode materials to the battery research community. The plan appeared reasonable to the reviewer.

Reviewer 2:

The reviewer stated that the future research efforts outlined make sense and build upon the current status and results.

Reviewer 3:

Given that the project must respond to the ever-changing needs of the research community, it certainly can be difficult to look ahead and plan for the chemistries and processes that the cathode community will need. It seemed to the reviewer that the team is knowledgeable about the state of the art and has likely developed plans for the future that will allow them to continue to meet the needs of customers and to contribute to the development of advanced cathode manufacturing processes. Having said that, it probably would be useful for the project to clearly identify a short list of those new chemistries and processes that are the highest priority to establish in the near term to be able to continually meet their mission. Some of that was implied in the presentation; it would have been better for it to have been more explicit.

Reviewer 4:

The reviewer gave a good rating as it is clear the PI has the fabrication and delivery of the samples under control but lacks a bit on plans (or articulated plans) to achieve the goal of a cost-effective scalable process. The reviewer wanted to know what the hurdles are and what the cost projects are to scale relative to the state of the art (SOA) for the equipment development and fabrications. More benchmarking of the materials produced by this process should be established relative to a commercially obtained high-quality material. The reviewer inquired about what the differentiating wins are with respect to cost and scalability and whether this process can be commercialized.

Reviewer 5:

Proposed future work plan seemed reasonable to the reviewer and follows the workflow outlined in the presentation. For what was identified as a "remaining challenge," the reviewer asked whether there are sensitivities of the LNO-based NMCs to calcination conditions and storage conditions. It was not directly clear how or if some of these challenges identified are part of the proposed future research plan.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer remarked that this project supports the overall DOE objectives by supplying large quantities of non-commercial NMC chemistries to the DOE battery research community and developing a new, cost-effective, scalable process for electrode manufacturing.

Reviewer 2:

The reviewer commented that this project (if successful at scale-up with consistent materials) fills an important need in the battery community for research labs (academic, corporate, government): the ability to provide meaningful and large quantities of new materials for testing with a low financial and time burden to outside labs.

Reviewer 3:

The reviewed viewed the project as clearly integral to the VTO program and the DOE objective to enable technology development for the electrification of vehicles. The project represents a key element in the VTO strategy and is playing a significant role in the broader success of the VTO program through the numerous collaborations that have been established.

Reviewer 4:

According to the reviewer, reducing cobalt (Co) content and increasing capacity are key pathways to reach the DOE goals.

Reviewer 5:

This project is important as a resource for custom materials not readily available in the community, which could benefit other projects. The reviewer liked the PI's involvement in other, broader projects, such as ReCell. The end game plans for commercialization and/or impact of this scalable process to impact the position of the country are a bit ambiguous.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer remarked that the allocated resources are appropriate for the scope of the project.

Reviewer 2:

Funding seemed appropriate to the reviewer for the scale of work being done.

Reviewer 3:

Given the current number of requests for materials, the resources allotted to the project appeared to be sufficient to the reviewer. However, the resource needs will scale with the number of requests for cathode materials so if the project is more successful in its interactions with start-ups, established industrial companies, and/or academia, then greater resources will be needed, or some sort of prioritization process will have to be established. But for now, the resources are judged to be sufficient.

Reviewer 4:

The reviewer could not make a clear judgment based on information presented whether there is sufficient funding and resources in place. The reviewer assumed for purposes of this review that the resources are sufficient.

Reviewer 5:

This project should state what major equipment was developed in the project with respect to expense. The reviewer wanted to know whether this Taylor Vortex Reactor pre-existed or has been purchased and/or modified heavily with DOE funds.

Presentation Number: bat168
Presentation Title: Process Development and Scale-Up of Critical Battery Materials - Continuous Flow-Produced Materials
Principal Investigator: Krzysztof Pupek (Argonne National Laboratory)

Presenter

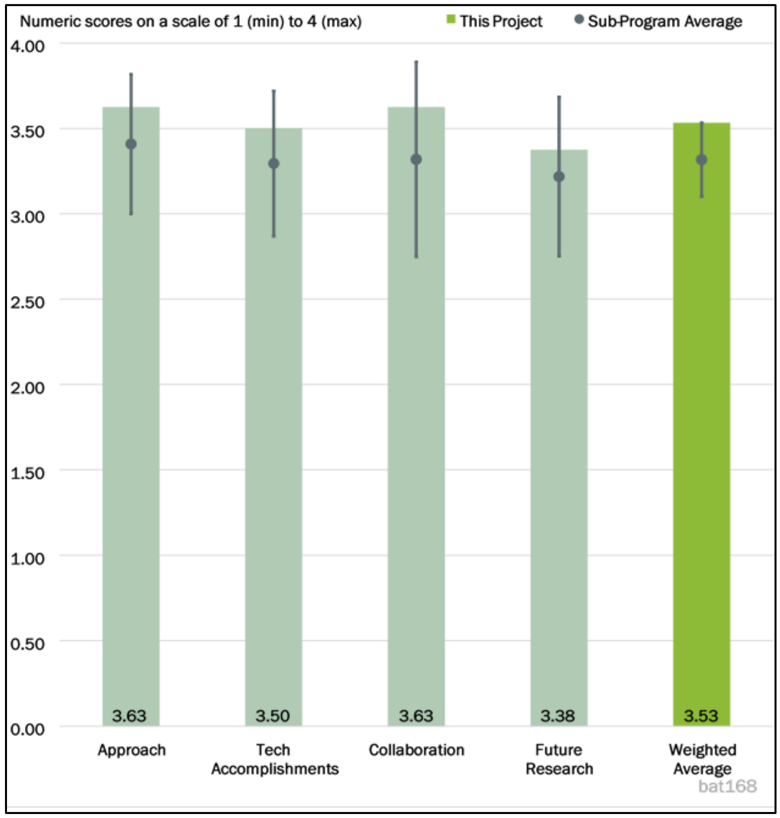
Krzysztof Pupek, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.



F Figure 2-5 - Presentation Number: bat168 Presentation Title: Process Development and Scale-Up of Critical Battery Materials - Continuous Flow-Produced Materials Principal Investigator: Krzysztof Pupek (Argonne National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer asserted that the synthesis of materials that are new electrolyte candidates is greatly needed. This is an area that may not have been sufficiently emphasized historically. The material targets that the group has selected are reasonable. Further, the project team's approaches to preparing the materials are sound and well considered. The team is handling hazardous materials and the appropriate precautions are taken in order for them to do this successfully and without incident. At this scale, the purification is batch level. This is appropriate as the materials are still made on a modest scale, but enough for the R&D community.

Reviewer 2:

The reviewer remarked that the continuous flow reactor technology has been developed and has a number of outstanding benefits, especially with respect to developing various electrolytes. Also the PI, the Materials Engineering Research Facility (MERF), seems to have a very well designed flow process for selection and downselection of electrolyte candidates that are of interest.

Reviewer 3:

MERF has state-of-the-art equipment for designing continuous flow processes for synthesizing electrolytes and solvents. The facility produces kilogram quantities of materials that facilitate property evaluation and testing in different locations using different instrumentation. This is a valuable asset for the battery community, according to the reviewer.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer noted that this project has been active for 11 years but has really shown results both in the development and continuous improvement of the continuous flow reactor technology (both in process equipment and in-situ characterization, such Fourier-transform infrared spectroscopy [FTIR]). The PI has demonstrated that this process works by fabricating and delivering an extremely wide variety of high-purity solvents to the community.

Reviewer 2:

The reviewer was impressed by the variety of salts and solvents that have been produced by the facility (Slide 30). The facility appears to have flexibility for synthesizing a wide variety of electrolytic compounds.

Reviewer 3:

The reviewer commented that the target materials were successfully prepared at a good purity level. Continuous processing was demonstrated for the material targets. Appropriate safety measures were used in the planning and the execution of the synthetic schemes.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer found that collaboration is intrinsically outstanding in this project as that is the basis for the decisions for fabricating novel electrolyte materials that are not easily obtained commercially. MERF has a mechanism to share these materials with the general United States (U.S.) research community and is a very highly collaborative resource.

Reviewer 2:

There is good synergy between the synthesis and characterization team members. The reviewer was impressed by the quality of the characterization data (Slide 17, for example).

Reviewer 3:

The reviewer stated that collaboration among the project teams is appropriate.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The future plans are based on excellent accomplishments and well within the instruments set up and the expertise of the PIs, according to the reviewer.

Reviewer 2:

On the excellent side, the reviewer acknowledged future electrolyte development and scaling, especially with the focus on ionic liquids (ILs).

In the good or less than good side, the reviewer suggested that the: PI needs to give more details about equipment development, hurdles, and direction to achieve a true continuous fabrication. There are not enough specifics in Slide 23 (Future Work) as much of it is written ambiguously.

Reviewer 3:

The reviewer stated that the future targets are appropriate. One suggestion for modification is that the most value from this effort is obtained when the group is focused on materials synthesis, purification, and characterization. Testing the materials in batteries would be better left to collaborators or partners.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer asserted that this project has tremendous current and future impact on the U.S. battery research community. It is much more difficult to obtain high-quality electrolytes than active electrode materials. If the reviewer were to continue funding one of the projects being reviewed, this would be it. It is a great example of highly practical, impactful work of the national laboratories and DOE to the U.S. battery research community. The reviewer would like to have seen more electrolyte projects and maybe fewer layered active material projects. It is also commendable that this project is supplying electrolytes at the same time as it is developing a somewhat novel and scalable synthesis approach for electrolytes with a number of positive attributes.

Reviewer 2:

The reviewer said that this is a unique and important facility for the battery community as it focuses on the electrolyte. Much of the synthetic focus is on the electrode materials.

Reviewer 3:

The reviewer indicated that new materials, including electrolytes, are needed. The detailed research explorations can only take place if the appropriate materials are available. This effort prepares the needed materials.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

According to the reviewer, this is a generously funded program that delivers excellent results.

Reviewer 2:

The reviewer stated that the group is well funded and at an appropriate level for the objectives put forward.

Reviewer 3:

The reviewer could not comment on resources as the burn rate and LOE of the project are not given. However, the project seems to be adequately funded over a long period of time, and funding should be continued.

Presentation Number: bat183
Presentation Title: In Situ Spectroscopies of Processing Next-Generation Cathode Materials
Principal Investigator: Feng Wang (Brookhaven National Laboratory)

Presenter

Feng Wang, Brookhaven National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

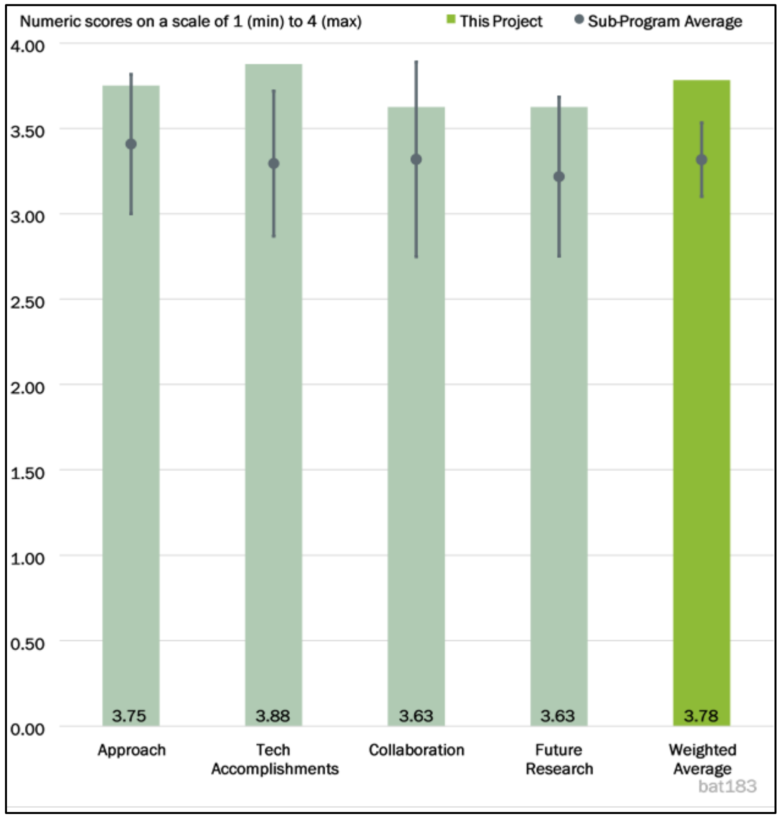


Figure 2-6 - Presentation Number: bat183 Presentation Title: In Situ Spectroscopies of Processing Next-Generation Cathode Materials Principal Investigator: Feng Wang (Brookhaven National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer called the approach used thorough and complete. The PIs use synchrotron methods (diffraction and spectroscopy) in addition to electron microscopy to study the complex processes that are necessary for synthesizing high-Ni cathode materials. In situ measurements indicate that the sluggish kinetics of formation of NMC811 is due to slow oxidation of Ni. This is an important insight into an increasingly important material.

Reviewer 2:

The reviewer said that is a well-structured project that aims to understand some of the most challenging aspects of NMC cathode materials both from processing and cost standpoints with the right collaborative team. Developing protocols for the synthesis of high-Ni cathodes are extremely critical for commercial realization of this class of cathode materials in the next generation LIBs, which is one of the main objectives of this project.

Reviewer 3:

In situ synchrotron X-ray spectroscopies, such as in situ X-ray diffraction (XRD), pair-distribution function (PDF), transmission X-ray microscopy (TXM), X-ray absorption near edge structure spectroscopy (XANES), and real-time tracking of elemental distribution, were conducted to study the processing of cathode materials in multiple length scales by the team, which is promising, according to the reviewer.

Reviewer 4:

The reviewer asserted that very nice work has been completed on this topic. The barriers listed mentioned low-energy density and cycle life, yet very limited amounts of performance data were included in the poster. To ensure that methods taken to improve cycle life were being mitigated, some performance data could have been included. Overall, the reviewer praised the project as very nice work.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer commented that the PIs have accomplished their goals by obtaining precise data that allow for understanding the reaction pathways of interest. The publication record of the PIs is outstanding.

Reviewer 2:

The reviewer stated that significant progress was achieved in various issues of high-Ni cathode materials, such as long-range, local structural change and elemental distribution during synthesis, kinetics of single-crystal and polycrystalline high-Ni materials during charge and discharge processes, etc. These issues are highly related to the electrochemical performance of high-Ni materials. The microwave synthesis of NMC materials is also promising, which is fast with low heat dissipation.

Reviewer 3:

The objectives of this project have been well addressed, and the results give clear guidance on the specific reasons for the structural evolution of high-Ni NMC cathode materials. The reviewer had a few questions to further clarify the methodology followed:

- When the in situ measurements are performed, what is the atmosphere for high-Ni NMC?
- Is microwave (MW) driven synthesis commercially viable at an industrial scale manufacturing of hundreds of MegaTons (MT) per year?
- Is the understanding of the structural aspects from a fast MW assisted synthesis transferrable to other methods of synthesis? If not, why not?

Reviewer 4:

The reviewer said that there was very nice work completed during this technical study. For the local redox, in situ TXM study, accepting the data is a bit doubtful because the entire color spectrum is not present. This reviewer explained that in a lot of Ni-rich NMC materials, there is some Ni^{2+} on the surface of most of the material. Here, the TXM data do not illustrate that. Additionally, during the live presentations, there was some discussion regarding the quality of the single-crystal material. The reviewer wanted to know whether an aggregate of single-crystal particles behaves similarly to polycrystalline material. More uniform, single-crystal material must be analyzed to ensure that the data are representative.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The work involved extensive coordination between BNL and ANL. The synergy between the partners was clear to the reviewer, as indicated by the wide variety of methods employed and the presence of several collaborators listed as authors on publications.

Reviewer 2:

According to the reviewer, the collaborative team is very well aligned to meet the project objectives.

Reviewer 3:

Collaborations were very clear to the reviewer. During the live presentation, it was a team effort, suggesting great collaboration between all the scientists involved in tackling the challenges and barriers listed.

Reviewer 4:

The reviewer asserted that the collaboration is excellent, and the duty of each team member is clear.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer said that the proposed future research is well planned and strongly related to the objectives from two perspectives: (1) improvement of high-Ni, low-Co, and Co-free materials, including morphology control, coating, doping, etc., and (2) development of new characterization methods.

Reviewer 2:

The reviewer commented that future work follows logically from the accomplishments. The focus on development of new, in situ approaches is noteworthy.

Reviewer 3:

The proposed work envisions understanding the low-Co and Co-free cathode materials during the next year synthesized via a TVR reactor. According to the reviewer, this is extremely important as industry is moving in the direction of reducing Co in the cathode material and eventually eliminating any Co.

Reviewer 4:

All the proposed future work is reasonable toward the goal. The reviewer indicated that the project team should ensure that there is a strategic approach toward understanding morphological control of the particles. If lithiation drives the morphology change, the reviewer wanted to know why and cautioned to be sure to have future work that aligns with answering this question.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that high-Ni content electrodes are of great importance in the quest for clean energy through rechargeable batteries. The fundamental knowledge obtained by the PIs will inform production of these materials.

Reviewer 2:

The reviewer noted that the project is highly relevant as it targets DOE's important objectives of both high-Ni NMC and low or no Co.

Reviewer 3:

The reviewer remarked that the work supports the overall DOE objectives. It advances energy while promoting scientific and technological innovation. Low-Co and Co-free materials are at the frontier of research, and this work supports those efforts.

Reviewer 4:

The reviewer indicated that this work is clearly relevant toward the goal. Studying the properties of high-Ni NMC materials in detail using advanced characterization methods is instructive for the improvement of electrochemical performance.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

The reviewer found that the resources available for the project, particularly the access to synchrotron-based instrumentation, enable accomplishing milestones in a timely manner.

Reviewer 2:

The resources are sufficient to meet the project objectives, according to the reviewer.

Reviewer 3:

The reviewer said that the resources provided seem sufficient for completing the milestones listed.

Reviewer 4:

The reviewer noted that sufficient work has been conducted to achieve the milestones.

Presentation Number: bat232
Presentation Title: High Energy Density Electrodes via Modifications to the Inactive Components and Processing Conditions
Principal Investigator: Vincent Battaglia (Lawrence Berkeley National Laboratory)

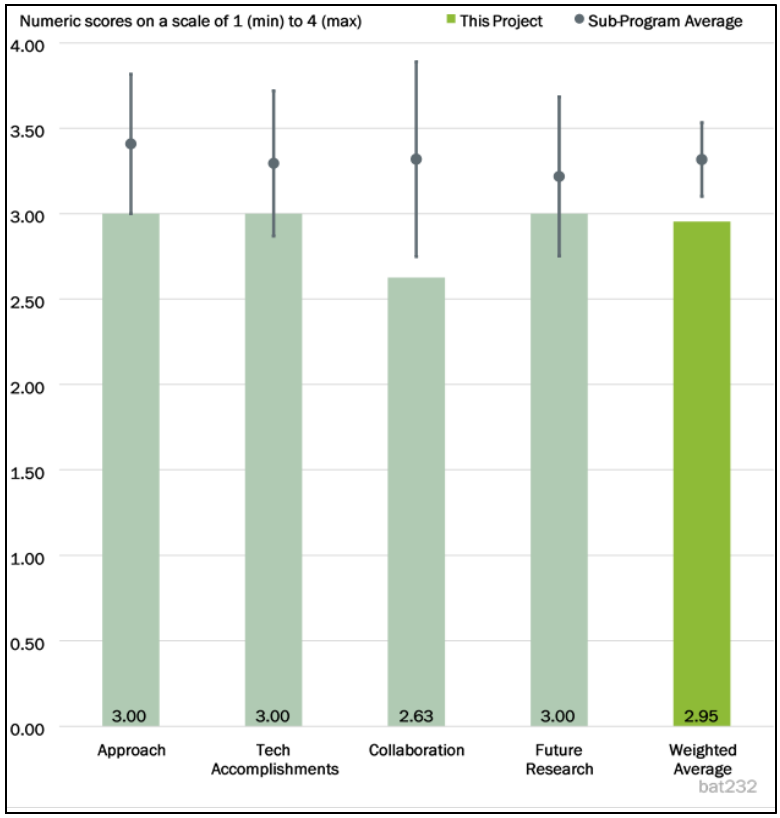


Figure 2-7 - Presentation Number: bat232 Presentation Title: High Energy Density Electrodes via Modifications to the Inactive Components and Processing Conditions Principal Investigator: Vincent Battaglia (Lawrence Berkeley National Laboratory)

Presenter

Vincent Battaglia, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer observed that the PI and the project team use standard methods to investigate the roles of inactive components and their processing conditions in determining the performance of high-energy cathodes. The study is systematic. The imaging approach could be improved with some synchrotron methods, which can give much high spatial resolution and chemical sensitivity.

Reviewer 2:

The reviewer said that the PI aims to gain fundamental understanding of the relationship between the physical properties and the performance of a thick electrode. The research covered micron-scale morphology and nano-scale interaction. The interaction between carbon and binder was investigated, especially the change of binder crystallinity.

It appeared to the reviewer that the process development and investigation involve many factors, which could interfere with each other. To get better understanding of such interference, design-of-experiment would be a good tool.

Reviewer 3:

The approach toward understanding the importance of binder content, mixing, and drying on hybrid pulse power characterization (HPPC) performance and cycle life of the positive electrode is well defined and being executed well. Electrode loading levels need to be clearly defined in the current year's accomplishments since it was unclear to the reviewer what electrode loadings are being optimized with different active material (AM) contents. More clarity on how this approach directly tackles the barriers of fast charge, cycle life, higher specific energy, and specific power needs to be provided.

Reviewer 4:

The reviewer found the project to be generally effective as it contributes to overcoming the barriers in the development of cathodes with low proportions of binder and conductive diluent and a high percentage of active material that improve the areal specific capacity of cathodes and hence specific energy Li-ion batteries. A specific objective of this project is to optimize the mechanical and electrochemical properties of high-loading electrodes with area-specific capacities greater than 4.5 mAh/cm^2. The approach being adopted includes evaluating various active material proportions of 92%-98% in the dense cathodes, keeping the carbon-to-binder ratio, but varying the processing conditions for improved rheology of the slurries without aggregates and for improved electrochemical performance, i.e., high-rate capability and cycle life of the cathodes and cells. This methodology will be extended to other DOE-VTO battery programs, e.g., eXtreme Fast Charge Cell Evaluation of Lithium-ion Batteries (XCel), cation-disordered rock salt (DRX), Co-free and R2R national laboratory collaboration, etc. Since this project is aimed at improving both performance and cost, it is directly addressing the barriers of EV batteries.

The reviewer commented that one of the weakness of this project is the need and relevance of this activity in a national laboratory environment. The optimization of cathode material composition and the process conditions (speed, mixing sequence, etc.) would be useful no doubt, but are highly dependent not only on the nature of active material, binder, and even carbon diluent but also the manufacturing equipment. This is the type of work typically done by the battery company. Quite possibly, similar optimization is being done by industry and hence there would be no technology transfer to industry in this regard. Also, the reviewer as to the relevance of this project, in the context of new "binder-free" or "dry" methods of cathode fabrication that are emerging recently. Another more specific question would be the rationale in keeping the carbon-to-binder ratio the same in this study.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The progress is in general satisfactory. The use of confocal microscopy is quite interesting. It appeared to the reviewer that the project is on schedule.

Reviewer 2:

The reviewer commented that the accomplishments in the budget year (BY) were to better understand the roles of carbon in the Li-ion electrodes, the importance of binder crystallographic structures, and the impact of carbon and temperature on the binder crystallographic structure. This knowledge is important for the overall project goal of the development of a high-performance, thick Li-ion electrode.

The reviewer suggested that the PI investigate carbon materials with different properties, e.g., surface area, crystallography, surface functional groups, etc., along with different binder materials. Again, statistical design-of-experiment would be beneficial.

Reviewer 3:

The project is on schedule, according to the published plan. The impact of mixing conditions and drying temperatures toward making high, active material content films has been studied and is being understood. The reviewer noted that comparison toward the specific key performance indicators for this project has not been clearly presented. More emphasis and studies on key performance metrics as a function of electrode loading is needed since high loading levels contribute directly toward solving the stated barrier of higher specific energy.

Reviewer 4:

There has been fairly good progress toward the projective objectives, according to the reviewer. Specifically, project results demonstrated that the active material content can indeed by increased up to 96% without compromising the performance, Likewise, the project team showed that the drying temperature could be increased to 180°C and the drying time reduced with no adverse effects on the performance. A new technique has been developed to track the aggregates in the cathode slurry. Finally, the process conditions have been optimized for NMC811 cathode. Overall, the progress is reasonable.

The reviewer found three weaknesses:

- Despite the good optimization carried out in this project, its impact is limited based on the specificity of the method used on the cathode material properties and process equipment (scale-up). The projected 25% improvement in specific energy and power density with less than 10% increase in cathode active material percentage (industry uses greater than or equal to 90% already) is quite a stretch.
- The cells and/or batteries need to survive environmental testing (vibration and shock) to validate the robustness of the cathodes with low binder contents.
- Cost analysis needs to be done to assess the relevance and impact of this modified cathode processing on the overall VTO goals.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted that the project is being conducted with collaboration with other similar groups working on electrode mixing, casting, and characterization. Collaboration is in the form of exchange of ideas and discussion.

Reviewer 2:

From the presentation, it was not clear to the reviewer whether the team currently has direct collaborations with partners. However, there is a great potential that their results can greatly benefit the understanding of the high-energy cathode design, and future collaborations could be built easily by the team.

Reviewer 3:

The PI's group collaborated well internally and with other national laboratories. However, it is highly practical research, and the reviewer suggested that closer collaboration with Li-ion battery manufacturers would be important.

Reviewer 4:

The reviewer commented that there are on-going collaborations with other DOE Offices, for example, the Advanced Manufacturing Office (AMO) for the R2R National Laboratory Collaboration and the Hydrogen and Fuel Cell Technologies Office (HFTO) for the Million-Mile Fuel Cell Truck Consortium. There are monthly technical meetings with other programs that are involved in electrode manufacturing and understanding the particle-level interactions.

The reviewer stated that the collaboration is non-specific and suggested that a more useful partnership would be with an industrial partner (battery manufacturer), if possible.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer said that the team has identified critical areas to improve in the future research plan. The team also recognizes some of the challenges and potential issues with their assumptions. The team has a plan to expand their studies.

Reviewer 2:

The reviewer opined that the future research was well planned and aligned to the overall objective. The PI understood the barriers well and the plan would address those barriers.

Reviewer 3:

Future work is geared toward further optimization of inactive materials with the goal of making better electrodes with high AM content. The reviewer recommended that these investigations be conducted as a function of electrode loading to determine maximum possible loading levels achievable to enable higher specific energy while maintaining other key parameters.

Reviewer 4:

The reviewer stated that the proposed future studies will focus on further optimizing the active material content and cathode fabrication and performing long-term cycle-life tests on the successful electrodes implemented in cells. Other carbons and binder (polyvinylidene fluoride [PVDF]) of different molecular weights will be examined. The future work is planned well and will have minimum risk.

According to the reviewer, the future work does not seem to be very novel, i.e., trying out new carbon and another MW PVDF. It may be more appropriate to work with new cathode formulations (higher Ni).

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer remarked that the project supports the overall DOE objectives by developing low-cost and environmentally friendly fabrication methods for dense and high areal capacity cathodes with high proportions of active materials for Li-ion cells. Overall, this is relevant to the DOE VTO battery programs and supports its objectives.

Reviewer 2:

Understanding variables affecting electrode manufacturing is important for achieving low-cost (lower inactive material content and faster processing), high-performance (high loading leads to high specific energy; better uniformity leads to better performance) batteries for EV applications in the reviewer's opinion.

Reviewer 3:

The reviewer stated that the project is highly relevant to support the overall DOE objectives. As a matter of fact, the method developed by the team can be applied to many different cathode chemistries that DOE VTO currently supports.

Reviewer 4:

The reviewer indicated that the project supports the overall DOE objective. It is critical to increase the active material load on an electrode in order to increase the energy density of a Li-ion cell. The proposed research on fundamental understanding of controlling parameters in the electrode process will lead the way to a high energy density thick electrode with decent power density.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The resources at the PI's lab are adequate to complete the task. The reviewer saw no issue of achieving the stated milestones in a timely fashion.

Reviewer 2:

The reviewer opined that resources are commensurate with the scope of the project and adequate to achieve the stated milestones.

Reviewer 3:

The reviewer commented that resources, which cover 20% of the PI's time and 33% of a research associate, are likely sufficient for the stated goals for the next project year.

Reviewer 4:

According to the reviewer, the PI has the access to more than sufficient resources to achieve the remaining milestones.

Presentation Number: bat240
Presentation Title: High-Energy Anode Material Development for Lithium-Ion Batteries
Principal Investigator: Cary Hayner (Sinode Systems/NanoGraf)

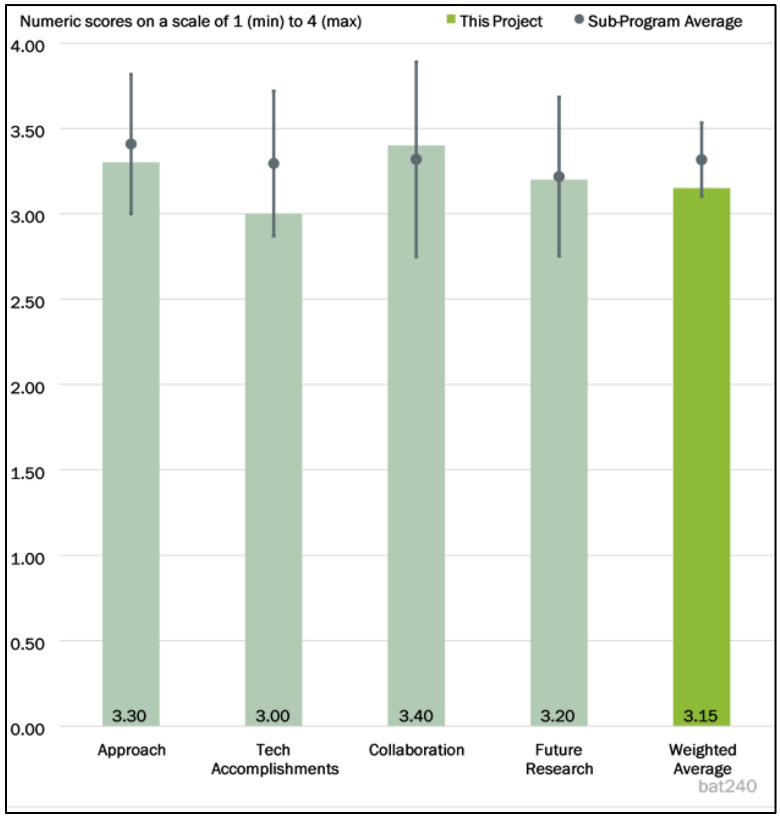


Figure 2-8 - Presentation Number: bat240 Presentation Title: High-Energy Anode Material Development for Lithium-Ion Batteries Principal Investigator: Cary Hayner (Sinode Systems/NanoGraf)

Presenter

Cary Hayner, Sinode Systems/NanoGraf

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

Nanograf's approach for this fiscal year was to optimize synthesis conditions for oxides of silicon (SiO_x) nanoparticles, to optimize graphene coverage of Si particles, and to examine the performance of PPG binders. Overall, the reviewer noted that each of these approaches is sound, with successful development of each thrust potentially resulting in an advance over the current state of the art.

Reviewer 2:

The reviewer said that the project is well designed and addresses the technical barriers of the silicon anode.

Reviewer 3:

The reviewer noted that the project addresses major technical barriers, including battery cost and energy, by developing Si-based anode materials.

Reviewer 4:

The barriers of the technology were addressed appropriately, and the approach is sound and well structured. It is a challenge to reach the project goals, but the reviewer suggested that maybe pre-lithiation is the key to being successful.

Reviewer 5:

The reviewer remarked that, overall, the technical barriers are adequately addressed. However, it would have been better if the barriers and project goal were presented in more quantitative way.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The team has made significant progress this fiscal year in each of the different thrusts. Data are provided that show optimal synthesis conditions for acid- and base-catalyzed SiO_x particles, the improvement of capacity and capacity retention of the SiO_x material with an undisclosed "Li containing surface treatment," the development of Si particles with high graphene surface coverage, and the enhanced performance and peel strength that PPG's binders provide. In the future, the reviewer looked forward to seeing how the graphene coverage impacts material electrochemical performance.

Reviewer 2:

The reviewer stated that novel progresses, such as those on novel Si-SiO_x material design, have been developed to dramatically improve performance at low cost. The project is a little bit behind the schedule. For example, barrier composition evaluation and the cost model have been completed, respectively, at only 67% and 33%.

Reviewer 3:

Progress has been made, the project seemed to be on track to the reviewer, the increase in lifetime and performance over the project time is good, and the collaboration within the project helps to solve key issues of the approach. A focus on industrialization and cost estimation is in its later stage of the project and is necessary to have a viable route to market.

Reviewer 4:

The reviewer indicated that the achieved cycle life is still far from the targeted 600 cycles. With graphene wrapping, the highest capacity is 1,500 mAh/g, which is lower than the targeted 1,800 mAh/g.

Reviewer 5:

A novel Si-SiO_x material was developed as low cost, but it was difficult for the reviewer to see cost competitiveness of the proposed synthetic route. The binder development is impressive. If a graphene coating helps volume expansion, as stated in the Approach, the reviewer would expect relevant measurement showing effectiveness of graphene coating on suppressing expansion. Also, it seems that different Si materials were used for different characterization—pre-lithiation, PPG anode binder study. The reviewer asked the PI to please label clearly which Si material was used for each test. Pre-lithiation work is confusing. If successful in developing material greater than 85% first-cycle efficiency (FCE), then the reviewer asked if pre-lithiation is necessary of it that is plan B. The reviewer also wanted to know what is unique about NanoGraf's pre-lithiation technique compared with already known methods.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer found the collaborations among team members to be excellent.

Reviewer 2:

The reviewer stated that the project team works with A123 to optimize electrolyte systems and additives to form stable solid-electrolyte interfaces (SEIs) and extend cycle and calendar life.

Reviewer 3:

In the field of carbon and graphene coating, a lot of knowledge is present in the different national laboratories, especially in terms of characterization techniques. The reviewer proposed that it would be nice to see Nanograf leveraging this knowledge. The interaction with PPG and A123 helps Nanograf to industrialize the material faster and secure a path to the market.

Reviewer 4:

The PPG collaboration for novel binders appeared to the reviewer to be really beneficial and has resulted in some very nice results. A123 is also helping with cell builds and electrode design.

Reviewer 5:

The reviewer remarked that collaboration with PPG is encouraging. However, it is difficult to see A123 contribution.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

All future work appeared to the reviewer to be entirely reasonable (continuing to develop materials, put them in cells, and scale them up) and should continue to advance the technology in a reasonable direction.

Reviewer 2:

Proposed future research looked okay to the reviewer, who asked about the reference cost in a cost target of greater than 50% cost reduction.

Reviewer 3:

The reviewer said that the team plans to scale up the synthesis and improve the performance, which are very challenging tasks. Some in-depth analysis and innovative solution will be necessary to overcome these challenges.

Reviewer 4:

The pre-lithiation path will be critical for the success of the project; also the cost estimation of the material will be very important to determine the success of the approach. Additionally, the team should consider safety investigations. The reviewer wanted to know how the new material and electrolyte compares to state-of-the-art material.

Reviewer 5:

The future work illustrated is sound. It was unclear to the reviewer if the developed anode works at a relatively higher temperature. Some evaluation of the cell made with the Si anode at high temperatures may be interesting if the budget is sufficient to support it. The analysis on gassing of the Si anode during cycle and calendar life testing may ensure if the material is suitable for vehicle battery application.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

Developing Si-based materials to increase battery performance and life as well to reduce costs aligns with DOE goals, according to the reviewer.

Reviewer 2:

To achieve energy density target, the reviewer indicated that a Si-containing anode with long cycle life and limited volume change should be developed and adopted. In this regard, this project supports the overall DOE objectives.

Reviewer 3:

The reviewer remarked that Si anodes are being considered as high-energy alternatives to graphite but suffer from limited capacity and calendar life. This project clearly aims at providing solutions to improve the cycling stability of Si.

Reviewer 4:

The reviewer stated that this project supports the overall DOE objectives by enabling Si anode.

Reviewer 5:

The reviewer commented that the project fully supports the DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The funding level seemed appropriate to the reviewer for this project.

Reviewer 2:

The reviewer stated that the allocated resource is sufficient to achieve the stated milestones.

Reviewer 3:

The resources seemed to be sufficient to the reviewer for the scope of the work.

Reviewer 4:

Resources appeared to be reasonable to the reviewer.

Reviewer 5:

The reviewer indicated that some aspects of the project would have benefited from working with a university.

Presentation Number: bat247
Presentation Title: Fast-Charge and Low-Cost Lithium-Ion Batteries for Electric Vehicles
Principal Investigator: Herman Lopez (Zenlabs Energy, Inc./Envia Systems)

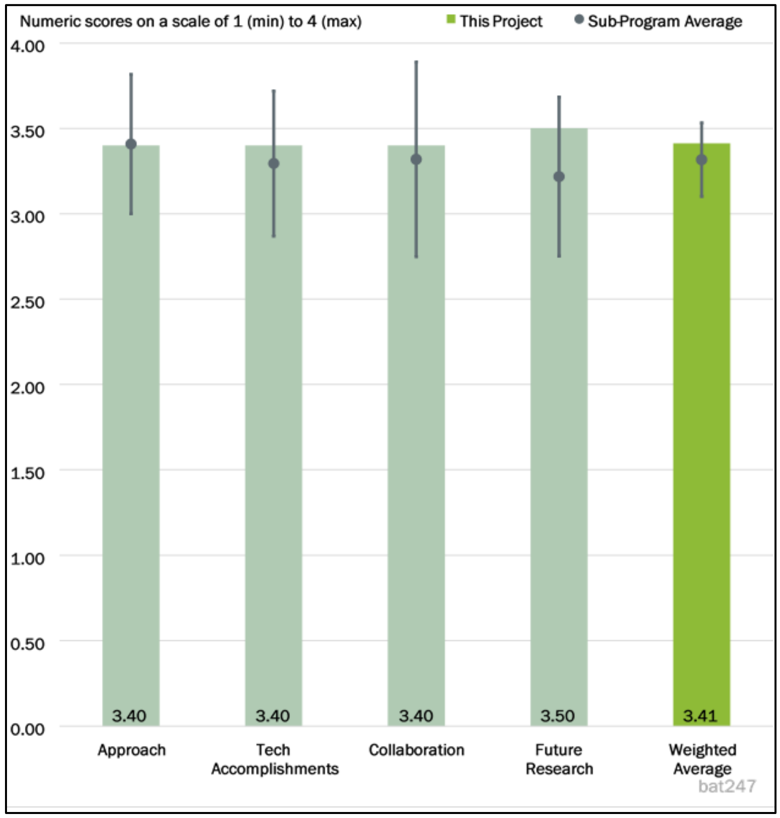


Figure 2-9 - Presentation Number: bat247 Presentation Title: Fast-Charge and Low-Cost Lithium-Ion Batteries for Electric Vehicles Principal Investigator: Herman Lopez (Zenlabs Energy, Inc./Envia Systems)

Presenter

Herman Lopez, Zenlabs Energy, Inc./Envia Systems

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer opined that achieving high energy density, fast-charge capability, long cycle life, and low cost—all at the same time—is extremely challenging and yet must happen for wider adoption of EVs. Zenlabs' strategy to address these barriers by adopting a Si anode with pre-lithiation and developing suitable electrolytes is good.

Reviewer 2:

The reviewer said that the project is well designed and addresses the technical barriers of fast charging.

Reviewer 3:

The project addressed technical barriers to improve battery performance, cost, life, and fast charging capability by developing novel electrolyte formulations and optimized cell designs, according to the reviewer.

Reviewer 4:

The reviewer indicated that Zenlabs uses an iterative, empirically driven approach to develop electrolyte formulations and pre-lithiation techniques for SiO_x-NMC cells. The overall goal is to improve capacity retention of cells that have been repeatedly fast charged. Electrochemical analysis of capacity retention and pouch-cell thickness analysis to quantify total outgassing are used as the primary characterization techniques.

Overall, the approach is good and has yielded impressive results, but without any understanding of how electrolytes should be engineered to provide improved performance.

Reviewer 5:

The project is well designed and addresses several questions important to the future development of Li-ion batteries. The chosen path is common but poses several risks. The reviewer suggested that topics, e.g., low-temperature performance and especially swelling, should be considered. The application of a fast-charge cell needs to be heavily synchronized with the mechanical aging of the cell, i.e., gas release, loss of electrode structural stability, and expansion over lifetime.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer reported that among the key technical accomplishments is an independently verified capacity retention of 80% after 1,000 cycles using a 4C charging rate. This is a very impressive result. Additionally, a 5C discharge capacity that is roughly 75%-80% of C/10 capacity is remarkable as well. Additional electrolyte formulations have also reduced gassing quite dramatically. Overall, the results are impressive, with the only negative being that no insight into the mode of improved performance is provided.

Reviewer 2:

The research from this project has developed cells with energy density, etc., to successfully meet the USABC cell 2023 goals, according to the reviewer.

Reviewer 3:

The performance targets are already met. However, the reviewer pointed out that the cost target is still not met, and a clear path to the target is not shown.

Reviewer 4:

The reviewer indicated that the progress made so far is good, the cycling number is impressive, and overall the project goals are within reach. However, some questions still remain open, i.e., gassing, swelling, and extreme temperature performance; a full validation over a temperature profile could provide useful insights. Also, the self-heating rate of the cell has to be considered as charging at high currents will ultimately increase the temperature of the cell and change the behavior of the load profile.

Reviewer 5:

Achieving greater than 1,000 cycles at 1C/1C cycle and greater than 800 cycles at 4C/1C cycle in a greater than 10 Ah cell form factor is very impressive. However, an increase in cell thickness by more than 200% during 65°C storage is problematic. Here are some questions from the reviewer:

- The reviewer asked whether has the project team measured cell thickness increase over the 1,000 cycles?
- The approach includes pre-lithiation development. However, pre-lithiation is not mentioned at all in the results. Was pre-lithiation applied to the 12Ah cell?
- It seems that the Zenlabs anode is Si-dominant, and the reviewer asked what the percentage of Si is in the anode.
- The reviewer understood that the cell gravimetric energy density (GED) is 315 Wh/kg at C/3 and asked what the initial GED is for the 4C/1C cycle.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer said that the collaboration of Zenlabs with the national laboratories is very good. Overall, the team seems to be well chosen.

Reviewer 2:

The successful collaboration across the team resulted in the good research progress, according to the reviewer.

Reviewer 3:

The reviewer commented that USABC, INL, SNL, and NREL are all listed as collaborators, although the INL collaboration appears to be most valuable to this point. Many results have been independently verified by INL.

Reviewer 4:

The reviewer remarked that collaborations are mostly with national laboratories in cell testing, which is adequately structured. The reviewer wanted to know if the pre-lithiation development is a Zenlabs in-house effort.

Reviewer 5:

The reviewer stated that the project team needs to work with equipment manufacturer to scale up pre-lithiation. The electrolyte part could leverage more collaborators.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

Future work—developing and applying protocols to understand calendar life, down-selecting electrolyte and electrode materials, manufacturing of pre-lithiation, and cell prototyping—is all reasonable and should allow the project to achieve stated goals, in the reviewer's opinion.

Reviewer 2:

The reviewer found the future work to be nicely planned, especially on the scale-up of pre-lithiation and electrolyte optimization to reduce degassing.

Reviewer 3:

The reviewer said that the proposed future research is well stated. However, considering the project ending date (July 31, 2021), it does not seem to be possible for the proposed future research to be done within the current project.

Reviewer 4:

The reviewer indicated that the project ended in July 2021.

Reviewer 5:

The reviewer noted that the described future study will facilitate the further development of the technology and its adoption for commercial applications. Considering the harsh working environment of electric vehicles, the high-temperature performance and cycle of the cells with the developed technology may be a concern and gassing may be potential a problem. It may be interesting if Zenlabs can weigh if the project team can leverage other projects funded by DOE, such as a shelf-life testing protocol (*https://www.nrel.gov/transportation/assets/pdfs/silicon-calendar-life-report-04012021.pdf*).

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer affirmed that the research is developing novel electrolyte formulations, a scalable pre-lithiation solution that enables the use of high-capacity silicon oxide anodes, and optimized cell designs that will result in LIBs capable of meeting DOE's goals on EV battery fast recharging and battery cost reduction.

Reviewer 2:

The reviewer responded positively and noted that higher energy density with fast charging rates is clearly important for car manufacturers.

Reviewer 3:

According to the reviewer, this project supports the overall DOE objectives by enabling fast charging.

Reviewer 4:

The reviewer indicated that the application of the technology fully supports the goals of DOE.

Reviewer 5:

The reviewer commented that this project supports DOE objectives.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

The funding for the existing project seemed appropriate to the reviewer. More funding on proposed future work may warrant the optimization of the developed technology for scale-up production.

Reviewer 2:

According to the reviewer, the resources are sufficient and well spent.

Reviewer 3:

Resources appeared reasonable to the reviewer for the stated milestones.

Reviewer 4:

The reviewer said that the resources are sufficient to execute the project and to achieve the milestones.

Reviewer 5:

The reviewer opined that some aspects of the project (e.g., mechanistic understanding of the performance-limiting factor) would benefit from working with a university.

Presentation Number: bat269
Presentation Title: An Integrated Flame-Spray Process for Low-Cost Production of Battery Materials
Principal Investigator: Chad Xing (University of Missouri)

Presenter

Chad Xing, University of Missouri

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 67% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 33% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

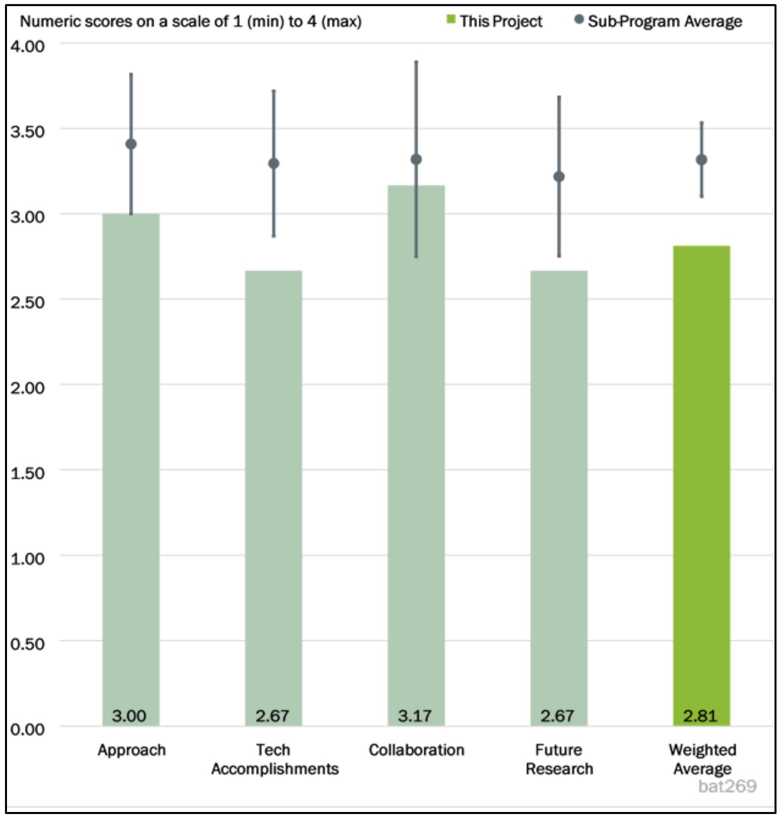


Figure 2-10 - Presentation Number: bat269 Presentation Title: An Integrated Flame-Spray Process for Low-Cost Production of Battery Materials Principal Investigator: Chad Xing (University of Missouri)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

According to the reviewer, incorporating a new solvent for the synthesis of cathode materials is an innovative approach. The solvent that has been proposed is a byproduct from a major industrial product and using it is a novel idea. The project objectives and technical milestones are well crafted by assembling a very collaborative team.

Reviewer 2:

The reviewer indicated that the goal was to scale up a flame spray process using glycerol as the solvent and combustion process. The approach is novel and interesting although the reviewer would have liked to see an economic analysis slide giving evidence for the economic advantage versus state of the art as the entire project is based on this attribute.

Reviewer 3:

It appeared to the reviewer that this project is near conclusion, but longer term it would be productive to determine whether a path toward 250 Wh/kg energy density cells at a lab scale is possible prior to designing and fabricating parts for a pilot production line. The reviewer recognized that there may be timeline challenges that required doing both in parallel, but from the presentation, it is not clear how the pilot production line is designed relative to the lab-scale setup and whether or not challenges observed at the lab scale will carry over to pilot scale and require substantial or non-optimal equipment redesign. Also, it would be helpful to see more detail on what it would take to scale this process to NCM 811, which is of interest longer term for EVs. While NCA is a good proof of concept, the materials set is less relevant to future DOE goals.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

After $2.5 million , the reviewer expected more than 80 cycles of NCA (which look decent) demonstrated. Data should have been shown versus a benchmark. The reviewer offered the following questions and observations:

- What about rate and, elevated temperature storage?
- There are plenty of great commercial NCAs to compare to. Where are these comparisons?
- The only basis for this project is economic advantage, which could be very attractive. Where is the end-to-end analysis showing this achievement?
- Why is scale-up occurring before parity with commercial SOA established?
- Is there any other advantage to the material made by this technique versus cost?
- Particle-size distribution should be analyzed.

Reviewer 2:

In general, flame spray can be inconsistent at scale. It was not clear to the reviewer if this process can theoretically scale to at least 10 kilograms of material and how consistent the particle morphology and quality will be relative to conventional processing based on what the project team has presented. The PI mentioned that the use of an “indirect flame” was better, and it was not clear what implications that has longer term for scale up. The reviewer had more detailed questions:

- Referencing Slide 5, and for the five cells, what is the cell size in terms of Ah that the project is targeting?
- Referencing Slide 7, are these data for coin cells or pouch cells? What is the charge-discharge protocol being used? For the cells that had good capacity at approximately 200 mAh/g, why were they only run for 10 cycles versus the other data set in Figure 1(B) that was run for more than 25 cycles?

Reviewer 3:

Electrochemical properties for the NMC materials synthesized using direct and indirect flame-spray pyrolysis have been reported. The project team has shown inferior performance for the direct flame pyrolysis, which has been attributed to the high temperature the powder is experiencing during the synthesis (approximately 1500° C). However, the reviewer asked that the following needs to be clarified:

- Is there any structural difference for the NMCs synthesized via both routes? Were any XRD studies done; if so, was there any cation mixing observed?
- What is the temperature experienced by the powders during the indirect flame pyrolysis?
- Any specific mitigation method, such as shorter time, etc., that may be employed to improve the direct flame pyrolysis method?

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer stated that the project has two collaborative team members, EaglePicher Technologies (EPT) and Storagenergy Technologies (ST), who are perfect for this project goals. ST will be the main scale-up partner for the materials, while EPT will be fabricating and testing the prototype cells in 250 Wh/kg battery cells using the material produced via this method.

Reviewer 2:

Partners and collaboration team seemed appropriate to the reviewer for the work presented.

Reviewer 3:

The project is collaborating with EaglePicher to fabricate 250 Wh/kg battery cells with this material. The project team should also benchmark it versus a commercially obtained material.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer commented that any novel synthesis method that disrupts the current method of battery manufacturing will be adopted if the material being scaled up to make larger format cells is critical. The future work that has been proposed encompasses the aforementioned items, which is an obvious must.

Reviewer 2:

The reviewer asked why there is a pilot-scale production line being planned when the advantages of this technique and performance have not been validated.

Reviewer 3:

The reviewer reiterated earlier comments and stated that longer term it would be productive to ensure that a path toward greater than 250 Wh/kg energy density cells at a lab scale is possible prior to designing and fabricating parts for a pilot production line. The reviewer recognized that there may be timeline challenges that required doing both tasks in parallel, but from the presentation, it is not clear how the pilot production line is designed relative to the lab scale line and whether or not challenges observed at the lab scale will carry over to pilot scale and require substantia, non-optimal, and/or costly equipment redesign. This was not clear, based on the content presented, and it is an integral, concluding task for the project.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer remarked that DOE's mission of low-cost, high-capacity NMC is well addressed in this project, and the cost analysis has been already done, which has shown that this method is economical over the traditional methods used.

Reviewer 2:

The reviewer responded affirmatively and said the project identifies technologies that could lead to an economic or performance improvement in the scalable manufacture of battery electrode materials.

Reviewer 3:

If successful, the project is relevant to DOE's longer-term goals. Based on the data presented, the reviewer had some concerns about the feasibility of process scaleup, especially for NCM chemistries.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

According to the reviewer, resources have been well spent over the project time, and funding should be sufficient to meet the milestones.

Reviewer 2:

It was not clear to the reviewer what the split is between EaglePicher and the PI. Also, plans to scale up should be evaluated in more detail relative to accumulated data to see if now is the time to pursue it.

Reviewer 3:

The reviewer assumed this project is near completion, but the funds provided for the results generated and milestones completed to date seem a bit high relative to other projects.

Presentation Number: bat293
Presentation Title: A Closed-Loop Process for End-of-Life Electric Vehicle Lithium-Ion Batteries
Principal Investigator: Yan Wang (Worcester Polytechnic Institute)

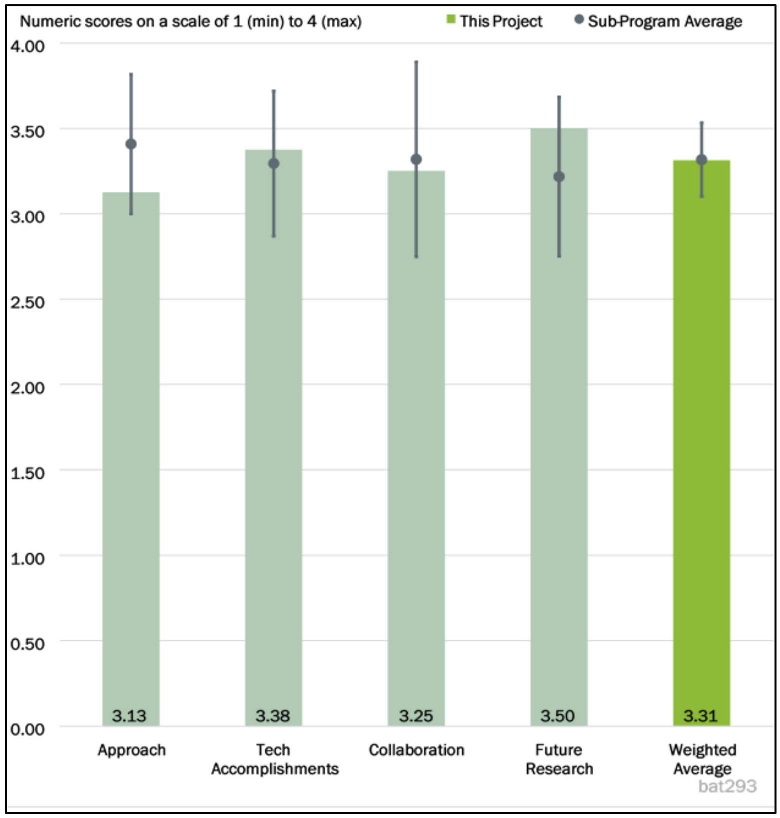


Figure 2-11 - Presentation Number: bat293 Presentation Title: A Closed-Loop Process for End-of-Life Electric Vehicle Lithium-Ion Batteries Principal Investigator: Yan Wang (Worcester Polytechnic Institute)

Presenter

Yan Wang, Worcester Polytechnic Institute

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The project addressed the challenges including cost and materials supply with recycled LIB materials. The testing of cells with recycled materials is essential to demonstrate the capability of the recycling process developed previously and to ensure the recycled materials can be used in LIB production.

Reviewer 2:

The reviewer found no detail on the recycling process described the report, which prevents an evaluation on the approach and design of the project.

Reviewer 3:

The approach appears to be to recycle spent NMC electrodes by using them or their raw materials to fabricate new electrodes, although the exact technology and procedure were not entirely clear to the reviewer. Large-scale cells (10 Ah) have been fabricated and compared to controls, and a model was developed for scale-up of the technology. However, as mentioned previously, it is not entirely clear what that technology entails.

Reviewer 4:

This reviewer indicated that convincing proof-of-concept is demonstrated, with recycled cathode material demonstrated at large enough quantities for relevant cell testing (greater than 10 Ah). However, the mechanism by which the rapid capacity fade of the recycled NMC622 occurs (compared with virgin 622 material) is not clear from this poster. To allow for commercial adoption of the recycled 622, the cycle life must be improved. The reviewer explained that changes to the particle composition or morphology may be necessary, and failure analysis will help to identify the right path toward achieving high cycle life. Perhaps collaboration with a cathode manufacturer could be beneficial to this effort.

While cell-to-cell consistency is demonstrated here, the ability to produce consistent 622 material across different production batches (i.e., with different feedstock inputs) should be demonstrated and is a key technical barrier to “closed-loop” cathode production.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The cost model for the scale-up plant seems to be well developed, and the comparison to control cells is reasonable. The reviewer noted that the project ended in February; so, less work has been done compared to projects that have run throughout the entire fiscal year.

Reviewer 2:

According to the reviewer, the preliminary testing of the cells made with recycled materials is promising though more efforts may be needed to improve recovered NMC materials.

Reviewer 3:

The reviewer commented that the measurable objectives are not explicitly stated. There is no way to verify the operation cost of the recycling process because the details are not presented.

Reviewer 4:

The stated that the cost model indicates process feasibility with a realistic $/kg value given and suggested that it would be helpful to show the cost model’s sensitivity to different feedstock inputs. As the amount of Ni greater than 50% cathode in the incoming cells increases, will the cost improvement versus virgin cathode widen?

While the cost model gives a feasible output for the Worcester Polytechnic Institute (WPI) process, the values given for the competing pyrometallurgical process seem quite high. This reviewer indicated that more explanation is needed to make a convincing argument here.

The reviewer further noted that one key point mentioned in the Project Objectives section is the ability to process spent batteries with non-standard chemistries, such as lithium titanate (LTO) and/or Si. No mention is made of the impurity content of the recycled NMC622, or how successful the process is at dealing with these non-standard cells. Cathode impurity specifications required for EV cells could also be a useful input from a cathode manufacturer or Tier 1 cell supplier.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

According to the reviewer, the collaborations among team members are excellent.

Reviewer 2:

The reviewer noted that A123 is the main partner and has provided guidance. ANL’s EverBatt model has also been used.

Reviewer 3:

There appears to be very close coordination between WPI and Battery Resourcers (BR), with good alignment on cost modeling. It was unclear to the reviewer to what extent A123 and auto original equipment manufacturer (OEM) partners are collaborating or offering feedback. One potential for input could be around the key performance indicators (KPIs) for cathode material and whether the performance demonstrated provides a realistic alternative to cathode cost-down efforts.

Reviewer 4:

A123 tests the cathode that the team recycled. The reviewer said that the team would be stronger if the team collaborates with industry to demonstrate a scaled-up recycling capability.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer found that the future work planned for Phase III is reasonable and is well illustrated. Since cathode materials move to high- Ni materials, such as NMC811 or even higher content nickel, it will be interesting to see if the recycling process is applicable to those materials. In addition, the testing on cells made with reactivated materials may validate if they are compatible with pristine materials in vehicle operation range.

Reviewer 2:

This project was Phase II of the program, and Phase III has been awarded. The plans for Phase III seemed entirely reasonable to the reviewer and are focused on reducing costs of the recycling process.

Reviewer 3:

The reviewer said that the project ended in February 2021.

Reviewer 4:

The reviewer commented that the project has ended.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer responded affirmatively and called the project highly relevant. Using recycled batteries as input into the cathode manufacturing value chain can lower the costs of batteries (and therefore EVs) as well as reducing the overall carbon dioxide (CO_2) footprint of battery and EV production. It can also help alleviate concerns around domestic supply of critical metals (Ni and Co).

Reviewer 2:

According to the reviewer, the research in recycling LIBs directly supports DOE goals for reducing battery cost and ensuring supplies of critical battery materials.

Reviewer 3:

The reviewer indicated that the development of battery recycling will be essential as more EVs come into the market. This project actively targets material recycling.

Reviewer 4:

The reviewer said that this project supports the overall DOE objectives by enabling cathode recycling.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer called the resources sufficient. Given the competencies of BR in producing cathode material, the required amount should be feasible assuming that the feedstock of spent batteries is available.

Reviewer 2:
Resources are sufficient for the goals of the project, according to the reviewer.

Reviewer 3:
The reviewer found that the funding level is appropriate for the project.

Reviewer 4:
The reviewer stated that the team has sufficient resources.

Presentation Number: bat315
Presentation Title: Process R&D for Droplet-Produced Powdered Materials
Principal Investigator: Joe Libera (Argonne National Laboratory)

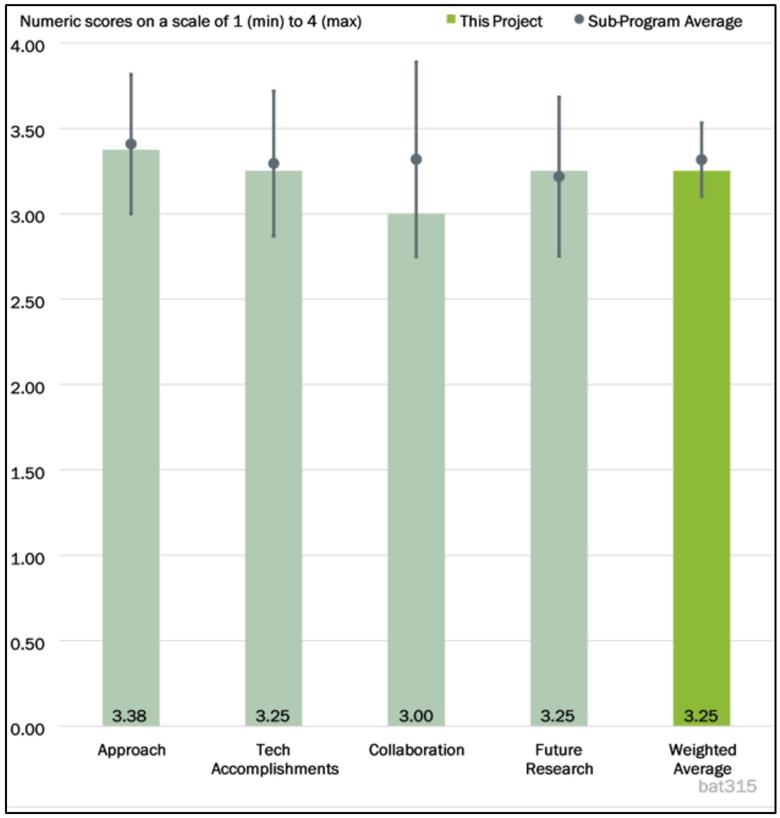


Figure 2-12 - Presentation Number: bat315 Presentation Title: Process R&D for Droplet-Produced Powdered Materials Principal Investigator: Joe Libera (Argonne National Laboratory)

Presenter

Joe Libera, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that this project aims to develop and optimize aerosol techniques, including flame spray pyrolysis (FSP), for producing LLZO-based SSE for lithium rechargeable batteries. FSP and aerosol techniques in general are an industry-proven production method and holds the promise for high-volume, low-cost manufacturing of SSEs. The team leverages the in-operando characterization techniques available at ANL’s FSP Facility to obtain useful insights and understanding of the manufacturing processes. Several techniques have been successfully added to the aerosol synthesis portfolio. They are used to synthesize several different SSE compositions, which support the research of various groups. Their study also reveals added benefits of the aerosol synthesis, such as the possibility of enabling one-step synthesis of layered cathode material without the calcination step and the co-sintering of LLZO green powder and cathode particles that leads to conformal coating of SSE on cathode surface. These findings are interesting and could further facilitate the manufacturing of solid-state batteries.

Reviewer 2:

The reviewer asserted that the approach to the project is strong and fills a need in the solid-state battery community to find alternate and scalable methods for material synthesis.

Reviewer 3:

Flame pyrolysis techniques have been in existence for decades by various companies, some in batteries, most not; the reviewer opined that the technology really deserves a deeper look as it offers a pathway to lower cost battery electrode materials. Even more importantly, it offers more intimate control of particle design and the promise of continuous-flow variable processes with very low cost. However, the reviewer suggested that the PI should do an economic analysis versus state of the art to truly establish that this route does have a cost advantage over state-of-the-art techniques.

Reviewer 4:

The reviewer indicated that Innovative material synthesis is one of the major areas mainly due to the economic incentives in the production of battery materials to drive the cost down at cell or pack level. Finding cheaper ways to synthesize battery materials is one of the predominant ways to achieve this goal.

Cost reduction has always been the basic need for battery material manufacturing, which the methods proposed. However, the presentation does not give a convincing argument for the need of the pyrolysis methods for battery material manufacture. Also, the overview slide is not showing the percentage complete as of now. The reviewer asked what the current status of the project is in terms of milestone accomplishments.

*Question 2: **Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.***

Reviewer 1:

The PI really seems to have a handle on the practical issues and is focused on transitioning the shortcomings of flame pyrolysis to achieve high-quality materials for batteries. The PI is addressing positive electrode materials and also lithium lanthanum zirconium oxide (LLZO). The PI is aware of the goal to densify particles and particle-size distribution is an issue. The reviewer liked the in-situ Raman addition to the process to gain a more intimate understanding of the calcination processes.

Reviewer 2:

The reviewer found the results interesting and, outside of material production, the approach of investigating co-sintering of the cathode and LLZO is an interesting pathway with the potential for larger impacts on solid-state batteries if successful. While there maybe differing opinions on what are the most promising solid-state chemistries to pursue, it is not clear if anything beyond the family of LLZO materials will be considered in the future or if other materials like sulfides are not compatible with this process.

Reviewer 3:

The reviewer mentioned a number of technical accomplishments achieved during the project period, including:

- Synthesis of aluminum (Al)-doped LLZO to support the evaluation of solid-state batteries by collaborators.
- Synthesis of LLZO to support the comparative study of polymer composite SSE by collaborators.
- Development and demonstration of the Slurry FSP and Slurry Spray Pyrolysis instruments.
- Direct formation of the layered NMC811 structure during FSP through the control of flame temperature, which could potentially eliminate the calcination step and simplify the cathode synthesis. Nevertheless, the yield of the layered phase is still quite low (8%), and additional process optimization is needed to improve the conversion rate.
- The team demonstrates that sintering LLZO green powder together with cathode particles could generate a conformal coating of cubic LLZO on an NMC cathode surface. This benefits from the small particle

size of the green powder and could potentially improve the charge transport kinetics. An impurity phase was discovered in the product, the abundance and distribution of which need to be further studied. In particular, the interface structure between the LLZO coating and NMC should be carefully characterized. It is important to confirm that the co-sintering process does not lead to the formation of detrimental interphase at the interface.

Reviewer 4:

The project started in 2016, and the progress shown is not sufficient enough to arrive at any conclusive remarks about the techniques proposed as the next-generation manufacturing method. With the data presented, it is hard to gauge the novelty of the method for the synthesis of cathode materials and/or solid electrolytes and expect a mass industrial adoption. The reviewer wanted to know if the team has filed for any patents in this area.

An LLZO commercialization milestone had been set for September 2020; however, this is listed in the Future Work. The reviewer asked what the exact reason is for the delay and whether it is because of an inadequacy in the facility or any fundamental constraints in scaling up this method.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

While the aerosol synthesis is mainly carried out at ANL, the ANL team collaborates closely with a number of institutions (Cabot, Northwestern, ORNL, Lawrence Berkeley National Laboratory [LBNL], and Purdue). SSEs synthesized at ANL are supplied to collaborators for different research projects. The collaboration is productive and meaningful.

Reviewer 2:

The reviewer noted that the PI has a select, but broad segment collaboration (a relevant industry like Cabot to academic users such as Purdue).

Reviewer 3:

The project has a good set of collaborations but given the large emphasis on solid-state in the battery community, the reviewer thought that this project would benefit from additional collaborations with both industry and academia to help further validate the utility of the materials synthesized. Especially for LLZO, involving another university or company would be helpful for additional comparative studies and validation of the material consistency and performance. The reviewer also encouraged the project team to publish or present on their work more to further disseminate their results and capabilities, which may help attract more potential collaborators.

Reviewer 4:

The project does seem to have a strong team including industry leader, Cabot Corporation. However, the results presented are not showcasing the collaborative efforts. The reviewer wanted to know if there are any scale-up efforts attempted with Cabot on any of the materials that are being synthesized at lab scale, whether the material produced for a large-scale processing will be shared with LBNL and ORNL for testing, and if there were any updates on the collaboration between ANL and the LBNL-ORNL team.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

Synthesis of 1 kg/day of LLZO is very critical to validate the feasibility and scalability of this process. This has been mentioned as future work, and the reviewer expressed interest in seeing the scalability and economics of this method of material manufacturing.

Improvement in various aspects of material synthesis with an intent of cost reduction is very critical at this point of mass electrification, and this project aims to achieve that in the next year, which the reviewer said is important. Low-temperature (T) garnet is another interesting aspect the project aims to study in the next year, according to the reviewer.

Reviewer 2:

The reviewer really resonated with the planned future research in Slide 13 and where the flame pyrolysis techniques could bring a novel approach and disruptive change in how controlled solid-state composites are fabricated. The single-crystal goal is also interesting.

Reviewer 3:

The proposed future research appeared reasonable to the reviewer, who suggested that the team complement their efforts in process optimization with defect (e.g., cation mixing and interphase formation) characterization to mitigate unwanted side reactions and defect generation. Also, the reviewer did not see electrochemical measurement data of the synthesized LLZO in the current report and inquired if someone on the team is working on this.

Reviewer 4:

Future work plans seem reasonable and logical based on the results presented. However, the reviewer encouraged the team to better define the challenges and incremental milestones needed to scale up the synthesis process to more than 1 kg/day+. From the presentation given, it was not clear what the barriers are in scaling from 1 kg/day to 10 kg/day, etc., or if the challenges are the same no matter the amount of material scaled up for synthesis. Given the broader project goals, this is an item that needs more effort and clarity in order to have a larger impact going forward. The reviewer would like to have seen more analysis work on the cost and energy required to truly scale up this approach to larger quantities. On Slide 5, Fiscal Year (FY) 2019 has an ongoing task of "Commercialize c-LLZO production"; it was not clear to the reviewer if the aforementioned questions are being addressed intrinsically here.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer really liked this project, the progress obtained, and the goals moving forward. The process is somewhat novel, but more importantly the novelty in the changes to the process to address its shortcomings could result in a disruptive change to the way materials are fabricated. Again, spray pyrolysis has been around for a very long time, but this PI has a handle on the morphological changes that need to be made and the potential advantages for single-crystal development and especially composite fabrication.

Reviewer 2:

Overall, the reviewer found the project and results presented to be of high value and of general interest to the battery community. This project is a key component of enabling better scaleup and wider research investigation of new battery materials, especially LLZO.

Reviewer 3:

The reviewer commented that this project supports the overall DOE objectives by developing high-volume, low-cost SSE synthesis techniques and supplying SSEs to the DOE battery research community.

Reviewer 4:

The reviewer asserted that any effort to reduce cost in any battery component will lead to the low-cost goal of DOE at battery cell or pack level of approximately $75/kWh. This project aims to get the cost reduced by introducing an innovative method of material manufacturing. Once the process has been proven scalable and economical, the reviewer remarked that combining it with improved electrochemical performance will enable this technology to be compelling enough for mass adoption.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer indicated that it is nearly impossible to make a robust comment without the LOE and/or loaded burn rate for the national laboratory. However, the reviewer believed that this project is one of the most efficient ever seen. Although it has been going on for 5 years, the reviewer believed that this is the type of project that deserves a continued moderate level of funding for long periods until it is time to build the next step in scaled equipment once viability is proven. It is a nice project.

Reviewer 2:

Resources seemed appropriate for now to the reviewer. It is unclear if more resources or equipment modifications will be needed in the future for larger synthesis scale-up.

Reviewer 3:

The team has a perfect mix of an industry leader, national lab, and university with appropriate expertise to carry out the proposed work, according to the reviewer.

Reviewer 4:

The reviewer indicated that allocated resources are appropriate for the scope of the project.

Presentation Number: bat355
Presentation Title: Development of High-Performance Lithium-Ion Cell Technology for Electric Vehicle Applications
Principal Investigator: Madhuri Thakur (Farasis Energy)

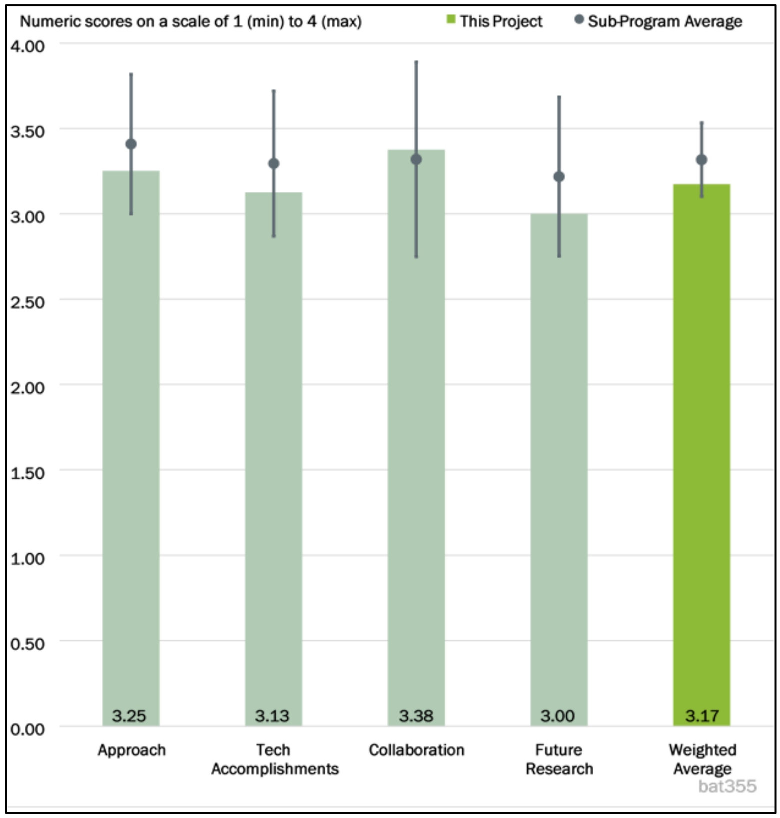


Figure 2-13 - Presentation Number: bat355 Presentation Title: Development of High-Performance Lithium-Ion Cell Technology for Electric Vehicle Applications Principal Investigator: Madhuri Thakur (Farasis Energy)

Presenter

Madhuri Thakur, Farasis Energy

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer noted that the approach is to optimize all materials in a Si-C composite/Ni-rich NMC cell to provide the best combination of performance and cost. This empirical approach resulted in some very nice cycling and performance metrics. Gen2 cells have approximately 330 Wh/kg energy density and were optimized beyond Gen1 cells.

Reviewer 2:

It seemed to the reviewer that major technical barriers, including binder, electrolyte life, etc., were considered in this project.

Reviewer 3:

The overall target of the project is very clear, and the team is focused on delivering. The approach seems to work although the poster presentation does not clearly specify the evaluation criteria for each component and material. The reviewer highly appreciated the independent analysis of the cells by the national laboratories, which seems to be working well.

Reviewer 4:

As two reviewer comments from last year pointed out, the project looks like a trial and error of the combination of existing technologies, which lacks a rational design.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer said that the initial performance targets have been reduced over the course of the project.

Reviewer 2:

The reviewer indicated that the team clearly showed the progress in the work. Points to consider to further develop the technology would be calendar-life aging at higher temperatures, swelling behavior of the cell, gas formation, and safety level compared to standard product.

Reviewer 3:

It appeared to the reviewer that all targets for the project were achieved. Although the cost ($0.10/Wh was the target) was not reported, the PI stated that the USABC cost goal was achieved.

Reviewer 4:

The developed cells seemed to the reviewer to meet the goals promised. The volt$_{min}$ (V_{min}) for baseline cells (3.0 V) and final cells (2.75 V) is different in the comparison table. It was unclear to the reviewer if the baseline cells have higher specific energy if its V_{min} changes to 2.75 V.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted that there is an outstanding number of contributors, and the workload and contributions seem to be balanced well.

Reviewer 2:

Many materials and characterization collaborators contributed to this project (ANL, LBNL, Daikin, 3M, Solvay, Celgard, Shin-Etsu, etc.). The reviewer stated that these are impressive collaborators.

Reviewer 3:

The reviewer opined that the collaborations among team members are excellent.

Reviewer 4:

The partners are more like suppliers. The reviewer said that true collaboration is lacking.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer stated that the project has ended.

Reviewer 2:

The reviewer commented that the project has ended.

Reviewer 3:

The reviewer pointed out that the project ended in September 2020.

Reviewer 4:

No future work was provided. It was unclear to the reviewer how the technology can be transitioned for application.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer observed that the goals of this project—develop EV cell technology capable of providing 280 Wh/kg after 1,000 cycles at a cost target of $0.10/Wh—are in direct support of DOE objectives.

Reviewer 2:

According to the reviewer, optimization of lifetime, cost, and energy density are all relevant to DOE objectives and targets of this project.

Reviewer 3:

The reviewer indicated that this project supports the overall DOE objectives by increasing the energy density of LIBs.

Reviewer 4:

The reviewer said that the project fully supported the DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer found that the resources for this project are appropriate.

Reviewer 2:

The reviewer indicated that the resources were sufficient and well spent.

Reviewer 3:

The reviewer stated that resources for this project are sufficient.

Reviewer 4:

The reviewer asserted that some aspects of the project would have benefited from working with a university.

Presentation Number: bat356
Presentation Title: Lithium-Ion Cell Manufacturing Using Directly Recycled Active Materials
Principal Investigator: Madhuri Thakur (Farasis Energy)

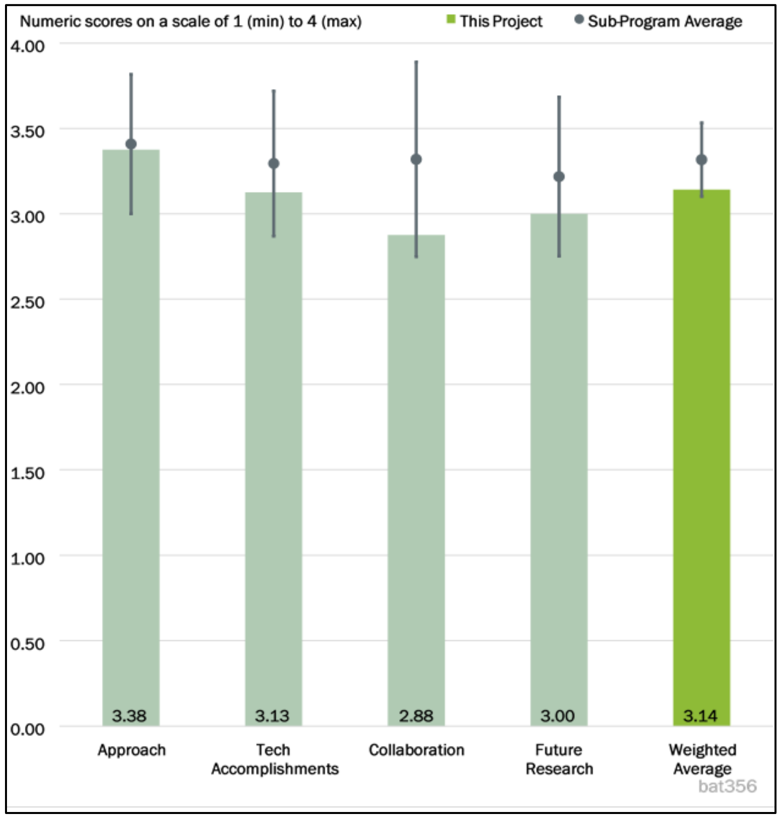


Figure 2-14 - Presentation Number: bat356 Presentation Title: Lithium-Ion Cell Manufacturing Using Directly Recycled Active Materials Principal Investigator: Madhuri Thakur (Farasis Energy)

Presenter

Madhuri Thakur, Farasis Energy

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The approach relies on the direct recycling of used battery cell components. The extraction of active materials follows a loop that the reviewer found interesting: electrode shredding, sieving, density separation, and material regeneration. Recycled materials are then used in electrode formulations that contain both recycled and fresh materials. Cost modeling is also performed to evaluate savings using this technology. The project is well designed and feasible.

Reviewer 2:

The effort of this project support DOE's goals by develop recycling technology for LIBs that will enable direct reuse of high-value active materials. The technical challenges of direct recycling process are addressed, according to the reviewer.

Reviewer 3:

The reviewer said that the tasks are well designed to meet the objectives.

Reviewer 4:

The ability to use mixed feedstock (i.e., different chemistry inputs) will be essential in the long-term as end-of-life (EOL) vehicle packs begin to represent a significant volume. The reviewer suggested that more work should be done to demonstrate the viability of this approach when multiple cell chemistries are used as inputs. The long-term impact of the impurities introduced by the direct recycling process (F) needs to be tracked.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The cells containing recycled materials had very similar performance metrics to cells containing only "pristine" materials, which the reviewer noted certainly serves as proof that the developed methods work. The cost analysis clearly shows an economic benefit to using recycled materials.

Reviewer 2:

The reviewer stated that the modified process for recovery scale-up for whole-cell feedstock has been developed. The cells built with the small quantity of recycled materials are almost comparable to those made with pristine materials though more future efforts may be needed to understand and optimize recycled materials. With further study on the process optimization and an increase in the purity of recycled materials, the developed technology may play an important role in LIB recycling. The cost analysis was not detailed, but it might have been provided in the final report.

Reviewer 3:

The performance targets are already met. However, the scalability of the approach remained questionable to the reviewer, especially the use of large amounts of non-water solvent.

Reviewer 4:

The data presented indicated to the reviewer that using recycled cathode material in the material supply chain is feasible. Data should also be gathered on long-term cycling and calendar life to examine the impact of the impurities identified from the recycling process on degradation behavior. More information on how the used cathode is "rejuvenated" would be helpful to understanding if this process can be generalized to larger scale LIB recycling.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The collaboration across the team members appeared excellent to the reviewer.

Reviewer 2:

The reviewer said that the PI works with a national laboratory to do characterizations.

Reviewer 3:

It was unclear to the reviewer if the national laboratories have provided technical input to the project beyond testing services. The main focus of the project seems to be on manufacturing scrap, internal to Farasis.

Reviewer 4:

LBNL is listed as a collaborator, but it was not entirely clear to the reviewer how its capabilities were utilized in this project.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer indicated that the project has ended.

Reviewer 2:
The reviewer noted that the project has ended.

Reviewer 3:
The reviewer said that the project ended in June 2021.

Reviewer 4:
According to the reviewer, no future work is described as this was the last year for this project; technical barriers and challenges for further word, however, were illustrated.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:
The reviewer affirmed that the ability to use recycled batteries back in the cathode supply stream would be very beneficial to the DOE targets. Cost and sustainability could be improved. Even if the proposed technology is only applicable to manufacturing scrap, it could lower production cost, which would help lower the cost of EV adoption.

Reviewer 2:
The reviewer commented that optimized recycling processes decrease the lifetime cost of energy storage technology and maintain availability of critical materials. This study of implementing recycled active materials informs future battery designs to improve recycling process efficiency.

Reviewer 3:
The reviewer noted that this project supports the overall DOE objectives by increasing the energy density of LIBs.

Reviewer 4:
The reviewer asserted that this project targets battery material recycling, which will be essential for large-scale, sustainable deployment of EVs.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:
Given that the main focus is on manufacturing scrap (not gathering EOL batteries), the reviewer remarked that a cell maker is uniquely positioned to develop and implement such a recycling approach.

Reviewer 2:
Resources are reasonable for the project, according to the reviewer.

Reviewer 3:
The reviewer indicated that some aspects of the project would have benefited from working with a university.

Reviewer 4:
The funding level and time appeared to the reviewer to be insufficient to support the research on direct recycling technique to a level that demonstrates the full capability of the technique.

Presentation Number: bat377
Presentation Title: ReCell–Overview and Update
Principal Investigator: Jeffrey Spangenberger (Argonne National Laboratory)

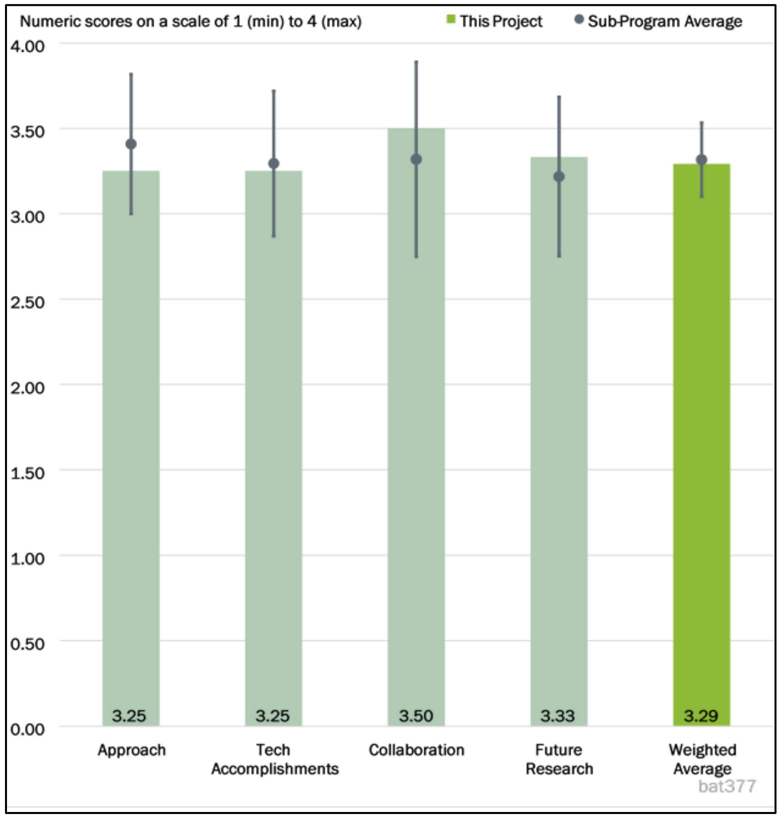


Figure 2-15 - Presentation Number: bat377 Presentation Title: ReCell–Overview and Update Principal Investigator: Jeffrey Spangenberger (Argonne National Laboratory)

Presenter

Jeffrey Spangenberger, Argonne National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 17% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer noted that this is a sharply focused and well-organized project to address the recycling of LIB materials. The team has been working on various process options to minimize risk with simultaneous assessment of the results and options.

Reviewer 2:

According to the reviewer, this project is an aggressive attempt to recycling by using direct recycling of cathode materials without the breakdown to individual metal ions. This has the potential to substantially reduce recycling costs, if successful. The project is well designed and feasible.

Reviewer 3:

The reviewer found that the continuous review of new ideas and stopping of efforts that do not show promise is a sound approach. Direct recycling is a hard problem that will take many iterations.

Reviewer 4:

The reviewer said that the project is well designed and feasible for the intended tasks, but the significant focus maintained on methods specific to direct recycling continues to detract from an optimal approach.

Reviewer 5:

This project seemed to the reviewer to have focused in on direct recycling of materials. This is a noble pursuit, but fraught with many challenges. The project team is aware of these challenges but does not explicitly call out if the team sees a feasible path forward. The role of industry to sort out these questions is not to be minimized, but the community would benefit from a clear statement (including the signatures of the industry partners) of whether or not any paths have been crossed out.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer indicated that the presenter demonstrated exciting electrochemical cycling of directly recycled NMC622 materials, which showed promising cycling performance after 400 cycles compared to pristine ("virgin") cathode materials. Although the performance is not as good as the original material, it demonstrates good first steps toward further development. The presenter did not cover how increasing impurities that may cause deleterious performance will be removed in future work.

Reviewer 2:

The reviewer observed that the project has been able to accomplish a number of significant results, such as studies toward direct recycling avenues, identification of the unit operations for preprocessing, separations and relithiations, appropriate solvent selection, recovery of copper (Cu) and Al, modeling studies, all with an overall eye toward sustainability. A good deal of IP has been generated as well.

While the above are clearly very encouraging given the early nature of these investigations, the reviewer reported that the recycling results shown from thermally and solvent-recovered cathodes performed significantly worse than the baseline. Hopefully, future work improves this aspect of the work significantly for these materials to be attractive commercially.

Reviewer 3:

The reviewer said that there has been demonstration of feasibility, but progress shows direct recycling is still far away even under the best of circumstances with relatively forgiving cathode materials (NCM622).

Reviewer 4:

The reviewer found that good progress has been made to identify options for recovering and reusing NCM111 and NCM622. However, battery testing of recycled NCM's still lags behind virgin NCM cathodes. This is a key step to demonstrate viability of the approach.

Reviewer 5:

The project has demonstrated useful progress in several key areas, but in general the outcome and progress for the direct recycling activity portions seemed to the reviewer for the most part to be expected and underwhelming.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

Collaboration and coordination across the project seemed to the reviewer to be very effective, and outreach to industry and related organizations seems excellent as well.

Reviewer 2:

The reviewer observed that the ReCell project has several ongoing collaborations with institutions at various levels, including universities and industry partners. The presenter mentioned actively trying to tour recycling centers to engage with industry players.

Reviewer 3:

The reviewer praised the team for having outstanding members, and it is great to see that ReCell is also working with the Battery Prize winners who might have a lot of out-of-the-box ideas, approaches, and solutions for recycling. It would have been nice to present a slide that identifies the activities of each of the individual team members and awardees.

Reviewer 4:

The reviewer stated that the interaction between the organizations is evident from the slides. However, deeper and more meaningful industry interaction would be appreciated, particularly with respect to the down-selecting of pathways as mentioned previously.

Reviewer 5:

The reviewer said that the team has a diverse background and capabilities.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The presenter highlighted that the future work would focus on demonstrating a recycled battery in real applications and improving its performance. The reviewer found this to be a critical step toward understanding the feasibility of using this approach and looked forward to seeing the results.

Reviewer 2:

According to the reviewer, the proposed future research captures all the key aspects of recycling. However, as it is obvious, if the materials are not at par with their commercial counterparts both from performance and cost points of view, then there will be no motivation for the cell manufacturers to use them. This task should be of the utmost significance.

Reviewer 3:

The proposed future work is sound, but the reviewer would like to have seen more focus on closing the performance gap between recycled and virgin NCM cathodes.

Reviewer 4:

The proposed future work seemed appropriate to the reviewer based on the work done to date, but the barriers to realization of some of the proposed technologies do not seem to have been fully considered. Alternate development pathways or possibilities for alternate implementations seems to be usefully open.

Reviewer 5:

The reviewer would really like to have seen very close connections to industry here.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

It was at last very heartening to the reviewer to see that recycling has now garnered significant attention from technical, environmental, political, and commercial considerations. In fact, this level of attention and commitment should have been given maybe 5 years ago when EVs were just slowly entering the market. We are now late in handling all these EVs that are coming to their EOL soon, and there is still no robust technology in place to tackle this issue. The reviewer appreciated the renewed efforts by the DOE in this area.

Reviewer 2:

The reviewer remarked that recycling is a critical step to create a circular economy for EVs. Without this, EVs will never be a mass market solution.

Reviewer 3:

The reviewer stated that recycling battery materials, especially cathode metals, can provide a critical pathway toward achieving overall DOE objectives of reducing battery costs for electric vehicles.

Reviewer 4:

According to the reviewer, battery recycling is a key step in a sustainable battery supply chain.

Reviewer 5:

The reviewer asserted that battery recycling is, and will continue to be, of key and ever-growing importance in supporting overall DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

As the reviewer previously mentioned, the industry and the country are both way behind in the recycling technology. Vigorous activities need to be initiated to catch up to develop robust, commercially, and environmentally attractive recycling technologies.

Reviewer 2:

Resources devoted to the project seemed sufficient to the reviewer and relatively appropriate within the overall DOE portfolio in the related time period.

Reviewer 3:

Resources appeared to be sufficient to the reviewer.

Reviewer 4:

Resources seemed sufficient to the reviewer.

Reviewer 5:

Sufficient resources were observed by this reviewer.

Presentation Number: bat382
Presentation Title: ReCell–Modeling and Analysis for Recycling
Principal Investigator: Qaing Dai (Argonne National Laboratory)

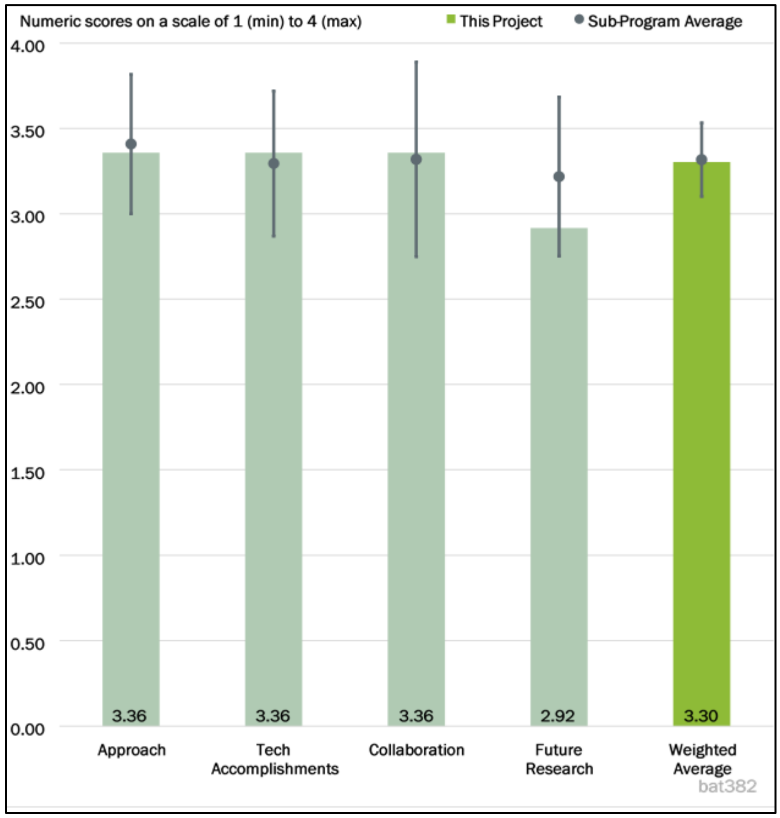


Figure 2-16 - Presentation Number: bat382 Presentation Title: ReCell–Modeling and Analysis for Recycling Principal Investigator: Qaing Dai (Argonne National Laboratory)

Presenter

Qaing Dai, Argonne National Laboratory

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 86% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 14% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

This reviewer remarked that the approaches taken to decrease recycling cost and then use recycled material for LIB remanufacturing will lower the cost of these batteries, resulting in an increased adoption of green energy technologies. The Principal Investigator's (PI) approach offers a winning combination to the automotive and renewable energy industry.

Reviewer 2:

The reviewer stated that the project is focused on developing models to show the viability of recycling Li-ion cells and will be extremely useful for companies and government agencies planning on investing capital in battery recycling.

Reviewer 3:

The reviewer commented that it is very nice to get the quantitative data indicating the necessity of recycling LIBs. Through EverBatt and Lithium Ion Battery Resource Assessment (LIBRA) models, meaningful data were obtained and assessed for the sustainability of LIB recycling.

Reviewer 4:

The reviewer asserted that EverBatt and LIBRA are important tools in evaluating the market relevance of any new battery recycling technology. These recycling technologies are needed to be implemented immediately in industry, and these tools help in realigning the focus of the research toward things that are more practical and something that can be actually implemented.

Reviewer 5:

According to the reviewer, useful modeling and simulation tools LIBRA and EverBatt have been developed in this project by addressing the need to evaluate the macro-economic viability of the battery supply chain as well as cost and environmental impacts of recycling processes.

Reviewer 6:

The basic approach to recycling analysis of using macro-economic and life-cycle analysis (LCA) modeling appeared sound and well reasoned to this reviewer.

Reviewer 7:

The reviewer found little substance in the slide deck to allow a sufficient review of approach. From what is available, the project team is trying to create a model to predict cost projections for 2025 and beyond based on 2020 and before material usage. The cathode material recycling model weighs heavy on the burden of Co, but the true issue in 2025 and beyond will be the availability of high-quality Ni. As chemistries shift toward Ni-rich NMC, the cost of Ni and its availability will be what drives the industry toward recycling.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

According to the reviewer, the two models are quite well developed to answer the important questions as to the viability and approaches needed to achieve LIB recycling.

Reviewer 2:

The reviewer stated that the modeling and simulation tools developed meet the planned goals and are in alignment with the schedule.

Reviewer 3:

The reviewer commented that Libra and Everbatt models are great accomplishments and could guide new businesses to enter battery recycling business with somewhat improved confidence.

Reviewer 4:

Technical accomplishments to date appeared to the reviewer to be on track and are very timely, considering the anticipated rapid increase in battery manufacturing that will be occurring over the next decade.

Reviewer 5:

The progress made meets all the project requirements set at the start of the project. The variables included are very useful and relevant to the objective. The reviewer asserted that there are still some corrections that would be needed, based on real data, but they can be made as a version update.

Reviewer 6:

The reviewer found good achievement by sharing the model results indicating the significant impact of LIB recycling on many different aspects in economy. It is very valuable information to get the cost and revenue breakdown associated with cell recycling. However, further assessment with the latest and near future materials would be more meaningful, and it would be very informative to get the source of the data for EverBatt model. For instance, manufacturing scrap rates would vary depending on key suppliers and informing data source will give more confidence to users.

Reviewer 7:

The project team has created a parametrized model that may be useful in predicting the true value of recycling of cell materials at various stages of life. Although the reviewer disagreed with the values being used, the tool being set up is novel and should allow for more robust inputs to guide it toward a more accurate solution in the future. It is unclear how this tool will be used going forward. This tool should be available to the greater battery industry to refine, improve, and utilize.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted that the project team is working well to incorporate modeling with data available from team.

Reviewer 2:

According to the reviewer, there is good collaboration and coordination across the project team.

Reviewer 3:

This reviewer noted great collaboration among many DOE labs and some well-known universities in the United States.

Reviewer 4:

The team consisted of researchers from several closely collaborated organizations and is well organized. However, it was unclear to the reviewer how the EverBatt model leverages previous modeling efforts, such as BatPaC.

Reviewer 5:

The reviewer indicated that there are good collaborative efforts among universities, national laboratories, and companies by providing them with technical knowledge in great depth along with commercial and business inputs leading to delivery of viable models. The reviewer suggested that it would be better to include OEMs in different industries to get their approximate roadmaps in LIB usage to better project the size of the recycling industry.

Reviewer 6:

The reviewer recommended the involvement of major industry partners. Considering the high value of manufacturing scraps, the reviewer expected that direct participation or partnering with a major Tier 1 battery cell supplier would be necessary to fully capture how recycling of manufacturing scraps can be practically implemented.

Reviewer 7:

The reviewer could not really tell what the collaboration is or is not from the reviewer slides. There is a wide list of national laboratories and academic authors, but the contributions are not clear.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer remarked that the project is ending in September 2021. But, as a final task, both teams will work with Battery Recycling Prize winners to inform their process development.

Reviewer 2:

The reviewer asserted that planned support to battery recycling prize winners is a great future plan. It will encourage new businesses and small businesses to work with ANL and other DOE labs.

Reviewer 3:

There are good plans for future work with the details on recent recycling processes. The reviewer stated that it would be good to see more environmental impacts of processes in the near future.

Reviewer 4:

The model will be applied appropriately. A little more detail would improve understanding of future plans, according to the reviewer.

Reviewer 5:

The reviewer commented that the future work described was not detailed though the proposed work seems reasonable.

Reviewer 6:

While both models appear to be useful additions, the reviewer found that very few specifics were provided regarding how future work would be conducted and how the models would be specifically used.

Reviewer 7:

The reviewer stated that it sounds like the model will be applied to "Battery Recycling Prize" winners but was unsure what this contest is or the significance it may have on utilizing this research.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

According to the reviewer, having a better understanding of battery supply-chain issues will be critical to increasing electrification of the light-duty and heavy-duty vehicle fleets in the United States. Both the LIBRA and EverBatt models and their incorporation of recycling analyses will assist with evaluation of battery supply chains within the United States and the role of recycling in continuing to both reduce the future cost of automotive battery packs and to improve a secure supply of critical battery raw materials.

Reviewer 2:

Reducing the need for foreign goods and raw materials is a core DOE objective. Recycling is key to that future. The reviewer asserted that recycling only occurs if financing occurs, and financing occurs only if a value can be seen. This model can help to draw conclusions on the value of investing in battery recycling.

Reviewer 3:

From the reviewer's perspective, it is very important to make an assessment of technology in relation to cost and industry relevance. DOEs objective of developing recycling technologies relevant to industry is highly dependent on making it cost effective, and this research project fits into that task.

Reviewer 4:

The reviewer remarked that battery cost is the main driver for the success of vehicle electrification. These project results greatly impact the DOE VTO objectives.

Reviewer 5:

The reviewer commented that the project supports the goals for battery cost reduction and environmental protection, and helps the future supply of battery critical materials.

Reviewer 6:

The reviewer found this work to be very important and showed the viability of recycling of LIB materials.

Reviewer 7:

The reviewer commented that lowering the price of LIB to $60/kWhr by 2030 is a great aspect of this project. Hope it materializes because if this happens, it will change the paradigm of eMobility.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

This reviewer indicated that the team is well resourced and gets help from DOE labs and universities.

Reviewer 2:

The reviewer stated that the project is appropriately resourced.

Reviewer 3:

The resources were sufficient to meet the project objectives, according to the reviewer.

Reviewer 4:

The resources appeared to be sufficient to the reviewer for the proposed efforts.

Reviewer 5:

The reviewer commented that no information was provided to indicate insufficient funding levels.

Reviewer 6:

The reviewer remarked that there were sufficient resources to deliver the initial results. As mentioned previously, the reviewer recommended that there be more involvement from industry (i.e., automotive, electronics, and utility) to develop more viable modeling tools.

Reviewer 7:

Approximately $15 million to produce this seemed excessive to the reviewer. The reviewer slide deck did not convey the detail of work done so the reviewer could only judge on what has been provided. Given that this model is only version 1.0, it will need critical alpha and beta testing phases to become a valuable tool. Some alpha testing should occur with the future work, but it is unclear how much the software will be improved from that feedback.

Presentation Number: bat386
Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Overview and Progress Update
Principal Investigator: Venkat Srinivasan (Argonne National Laboratory)

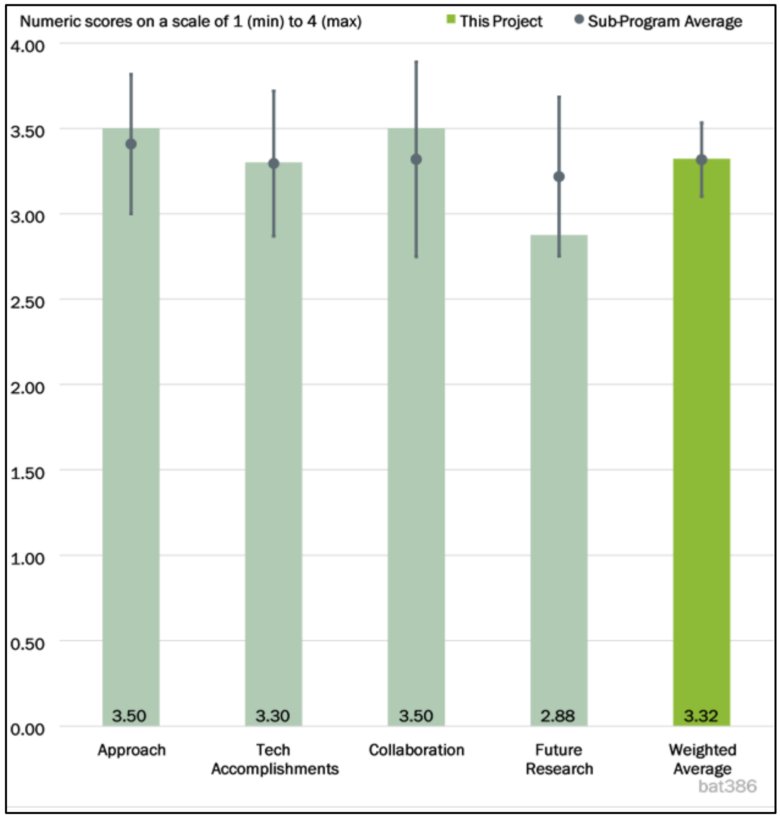


Figure 2-17 - Presentation Number: bat386 Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Overview and Progress Update Principal Investigator: Venkat Srinivasan (Argonne National Laboratory)

Presenter

Venkat Srinivasan, Argonne National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer opined that the project approach is well suited to national laboratories: understand the fundamentals of what is limiting fast charge and use and communicate that understanding so that the problem can be solved. In addition, the fast-charge problem is not due to one failure mechanism. This project does a good job at looking holistically at the cell to understand all areas for improvement.

Reviewer 2:

This reviewer indicated that basic material research to realize battery chemistry suitable for fast charging is an excellent approach. The Spider chart on Slide 3 serves the project PI and team very well to push the envelope of new battery technologies.

Reviewer 3:

According to the reviewer, this project showcases how to leverage the toolbox at the national laboratories. This project really focuses in on identifying the root cause of lithium plating. Although the conclusions are not relatively novel, the tools put in place are novel and the ability to quickly identify core failure will call for rapid development in this area. The challenge to the team is how to leverage this information into lower cost tools to further accelerate product development.

Reviewer 4:

The reviewer indicated that the project aims to approach the identified major issues of cell degradation limiting fast-charging capability of LIBs. Therefore, different approaches toward problem solution were chosen and processed by experts from the named partners. An additional barrier of low energy density and high costs for fast-charge cells was also identified and addressed.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that the PI provided a high-level description of the work done as well as the future work. The partner teams have proposed several different fronts for future work, which align well with the fact that multiple PIs are involved in the project.

Reviewer 2:

The reviewer remarked that the project shows key improvements in electrolyte, design, and diagnostic tools. Although these are not meeting the larger performance goals, this project puts the larger research industry on a pathway toward success.

Reviewer 3:

The AMR presentation and data indicated on Slide 10 demonstrate that great progress has been made since last year.

Reviewer 4:

The reviewer thought that the team has done a great job looking at failure mechanisms and developing techniques to detect failures like lithium plating. But, applying that knowledge to commercially relevant loadings needs to be pushed. Also, the reviewer thought that all this work was done using a graphite anode. Many EV cells contain some amount of Si; this should be included in the studies. The reviewer did not see that the goals and milestones of the project were communicated clearly at the beginning of the presentation, so it was hard to judge progress against those.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer thanked the PI for putting up a clear slide showing the distribution of the project. It was clear to the reviewer that the PI and team leveraged expertise from across the team, which has led to a successful project. This project should serve as an example of excellent cross-lab collaboration.

Reviewer 2:

The reviewer asserted that the PI showed clearly that the different researchers within this project are doing excellent work in team’s fields of expertise as well as interconnecting well considering the topics that require collaboration of different teams.

Reviewer 3:

The U.S. national laboratories have done a good job coordinating on deep dive projects, such as voltage fade, Si anode, and now fast charge. The reviewer said that this is great teamwork.

Reviewer 4:

This reviewer noted great collaborative work between Venkat Srinivasan and Sam Gillard and reported that all contributors are indicated on Slide 7. This is a great ecosystem DOE has created to solve difficult science and engineering problems.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer stated that getting 6C chemistry will serve the automotive industry well.

Reviewer 2:

The proposed future plans are well focused on the identified problems. However, the question remaining from the reviewer is how these approaches can be adapted from laboratory work to real-life, industrial application, as the capability of fast charging is supposed to be a game-changer for broad customer acceptance (or better, the end of range anxiety).

Reviewer 3:

Spending a lot of effort getting good cycle life on 3 Ah/cm^2 cells might not be the right direction. The reviewer encouraged the team to start working on more commercially relevant loadings with EV energy-density targets. Industry does not care about the lower loadings.

Reviewer 4:

Not applicable was indicated by this reviewer.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer asserted that widespread EV adoption can only happen with consumer acceptance. The development of fast charge minimizes range anxiety and opens the market to a large number of consumers who do not have a place at home to charge their vehicles.

Reviewer 2:

The reviewer stated that fast charge is a key step toward passenger EVs, and this project positions researchers to develop toward the fast-charge goals.

Reviewer 3:

Extremely relevant work for the U.S. automotive industry was noted by this reviewer.

Reviewer 4:

The reviewer called the project highly relevant to DOE's objectives and, if fully successful, would enable different approaches and routes to fast-charging cell design to avoid the side effects of enhanced cell degradation.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The value of the output is in line with the reported spending, according to the reviewer. The team had clear access to high-power unique tools within the national laboratory portfolio.

Reviewer 2:

This reviewer observed a well-resourced team led by a very knowledgeable PI, Venkat, in collaboration with Sam.

Reviewer 3:

The reviewer stated that the resources appear to be adequate for completing the tasks within the mentioned time frame.

Reviewer 4:

The reviewer commented that the work across the national laboratories ensures adequate resources, skill sets, and technologies to make progress on this important work.

Presentation Number: bat402
Presentation Title: Improving Battery Performance through Structure-Morphology Optimization
Principal Investigator: Venkat Srinivasan (Argonne National Laboratory)

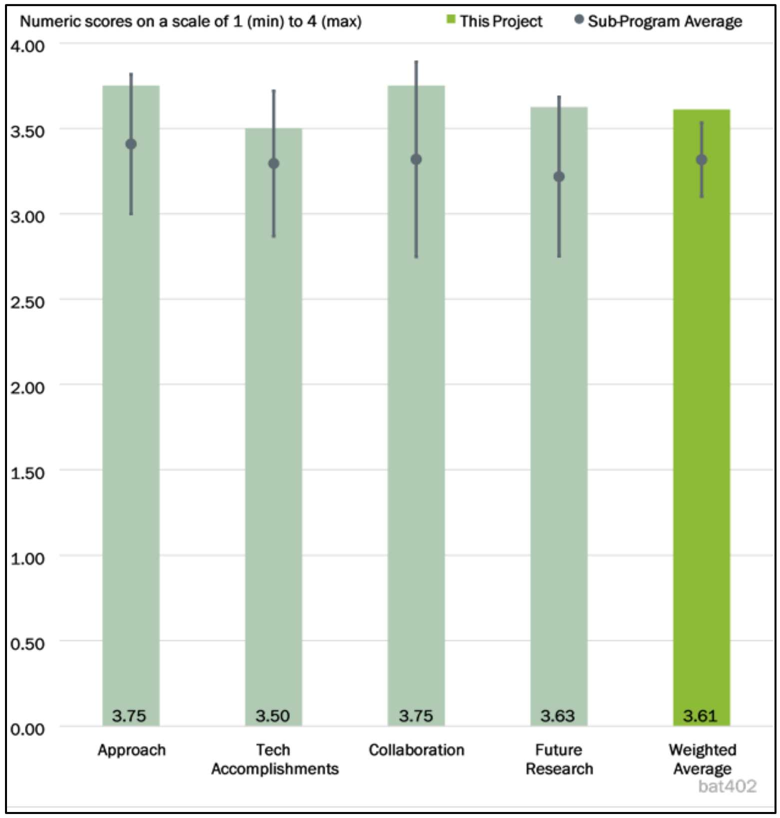


Figure 2-18 - Presentation Number: bat402 Presentation Title: Improving Battery Performance through Structure-Morphology Optimization Principal Investigator: Venkat Srinivasan (Argonne National Laboratory)

Presenter

Venkat Srinivasan, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer called this an outstanding project that approaches synthetic challenges by a combination of experimentation and phase field models. Particle complexity, a parameter that is difficult to quantify, is evaluated rigorously by a judicious choice of experimental approaches. In addition, effects such as densification of ceramic electrolytes are studied and modeled with high fidelity.

Reviewer 2:

The approaches of calculations and simulations are applied to various systems to predict the process of co-precipitation, calcination, and densification. The approaches are important, according to the reviewer, as they can guide the experiment to be more effective.

Reviewer 3:

The reviewer commented that the approach taken by the team is highly novel and can have great impacts on the field.

Reviewer 4:

The approach is very clear and concise. One barrier was that there was limited control of the structure and morphology during NMC cathode synthesis. It is still very much unclear what promotes particular morphologies during synthesis. The reviewer wanted to know if there is a method to elucidate reasoning for certain morphological control. Transition metal selection has a certain influence on morphology, but the reviewer asked about what drives the primary particle morphology in the transition metal.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

This is an ambitious project, and the PIs have made significant progress. The reviewer praised the quality of the publications as outstanding.

Reviewer 2:

The reviewer stated that the team has made major progress toward understanding the formation process of different battery materials. The in-situ synthesis work is interesting and novel.

Reviewer 3:

The synthesis condition or parameters in each work were studied in detail, such as temperature, time, pressure, ionic concentration, etc. The promotion of layered structure by the pre-conversion of $Ni_{0.8}Mn_{0.1}Co_{0.1}(OH)_2$ to cubic $Ni_{0.8}Mn_{0.1}Co_{0.1}O$ is especially promising, which is helpful for obtaining high-Ni materials with high quality. The only concern from the reviewer is what the advantage of the carbonate precursor is compared with the hydroxide one.

Reviewer 4:

There have been great efforts made toward tackling the barriers. The calculations and simulations show how primary particle morphology could be deciphered. It would be nice to couple theoretical modeling to experimental data to correlate morphology to performance indicators, like capacity fading and Coulombic efficiency. The pre-converted cathode material work was very impressive, but the reviewer was unsure if this reaches the target of decreasing overall cathode synthesis cost since the calcination process is longer with this added process. With the LLZO work, practical temperature and pressure systems need to be analyzed. Very nice baseline work is underway for LLZO densification.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The work is highly collaborative, involving X-ray diffraction, microscopy, thermodynamic modeling, and phase-field modeling. The coordination of different aspects of the work is outstanding, according to the reviewer.

Reviewer 2:

The reviewer stated that there are very good collaborative efforts between the scientists working on the project. In this work it is important to ensure that theoretical and experimental work are complimentary. Neither stand alone well without scientific doubt.

Reviewer 3:

The reviewer noted that the team is highly collaborative across multiple research groups funded by VTO.

Reviewer 4:

There is strong collaboration, but the reviewer was wondering about the contribution of each collaborator.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The problems identified—the reason for the formation of disk-like particles observed by Battery Materials Research (BMR) PI Wang, the surface reorganization of LLZO, and the possibility of enabling lower energy processes by starting with low-melting precursors—are important and significant, according to the reviewer.

Reviewer 2:

The reviewer said that the future work plan about further improvement of synthesis is clear and complies with the milestones.

Reviewer 3:

The team has clearly identified major research challenges and a plan to resolve them. If the team plans to use the imaging method to study the lithiation progress, the reviewer suggested that the mobile nature of melt Li precursors should be considered.

Reviewer 4:

The reviewer recommended that a part of the future work should also include the ab initio molecular dynamics (AIMD) simulation for nickel oxide (NiO) and LiOH when there is no O adsorbed at the surface (inert surface, nitrogen). This was discussed with the presenters during the live presentation. This would further convince the reviewer that lithiation of the intermediate cubic phase is promoted by surface oxygen. All other future work suggested is on a par with the milestones mentioned.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer indicated that the PI has done well to identify the important barriers that must be resolved to improve the performance of rechargeable LIBs.

Reviewer 2:

The reviewer found the project to be very relevant and critical to DOE in terms of building up U.S. manufacturing capability in advanced battery materials.

Reviewer 3:

The work supports the overall DOE objectives. The reviewer said that the work advances energy research and promotes scientific and technological innovation.

Reviewer 4:

The project is related to the synthesis of NMC cathode materials and SSEs, which supports the overall DOE objectives well, according to the reviewer.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer stated that the PI has used the resources well to achieve the set milestones in a timely fashion.

Reviewer 2:

The reviewer identified no weaknesses.

Reviewer 3:

The resources seemed reasonable to the reviewer for the projects, and the goals are relevant toward reaching the overall milestones.

Reviewer 4:

The resources are sufficient for the project to achieve the milestones, according to the reviewer.

Presentation Number: bat441
Presentation Title: High-Performance Electrolyte for Lithium-Nickel-Manganese Oxide (LMNO)/Lithium-Titanate (LTO) Batteries
Principal Investigator: Jennifer Hoffman (Gotion)

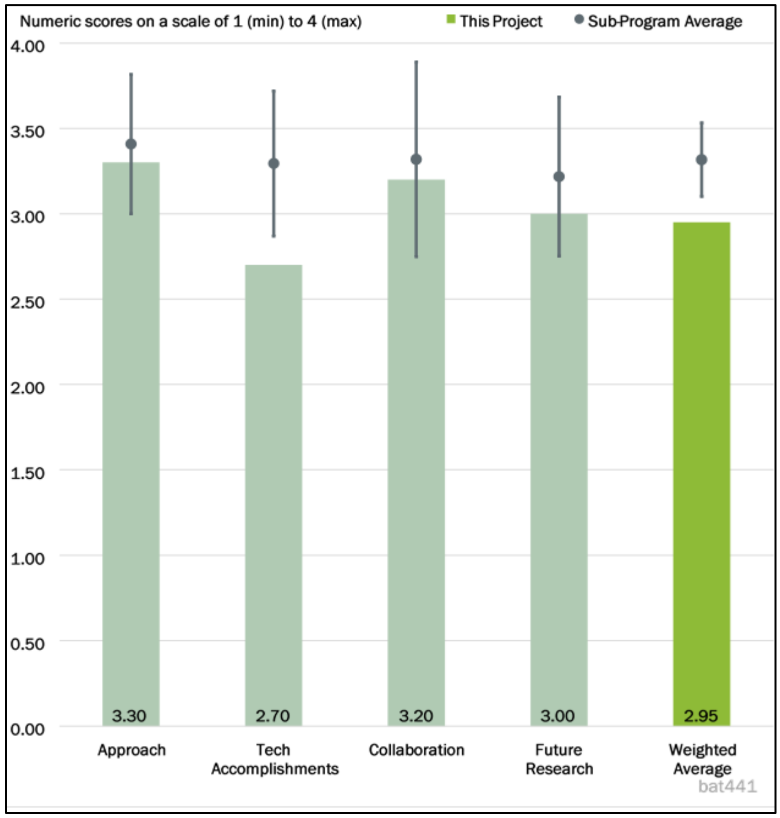


Figure 2-19 - Presentation Number: bat441 Presentation Title: High-Performance Electrolyte for Lithium-Nickel-Manganese Oxide (LMNO)/Lithium-Titanate (LTO) Batteries Principal Investigator: Jennifer Hoffman (Gotion)

Presenter

Jennifer Hoffman, Gotion

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

80% of reviewers felt that the project was relevant to current DOE objectives, 20% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 20% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer asserted that the efforts of developing electrolytes and additives in support of fast charging for cells with LTO and lithium nickel manganese oxide (LNMO) are aligned with the DOE goals and address the same major barriers for battery fast charging.

Reviewer 2:

The reviewer said that the technical barriers are properly addressed.

Reviewer 3:

The tasks are well designed to meet the objectives. The reviewer proposed that a more rational strategy can be used, instead of trial and error.

Reviewer 4:

Given the circumstances last year, this reviewer described the project renovation and newly refocused project development plan as good. The focus on carbonaceous anodes will help to increase the project output, although it would be nice to also see a very safe and stable LTO- high voltage (HV) LMNO cell being developed. Multi-layer pouch cell testing is a very viable way to investigate and continue the progress. Extended lifecycle testing and a direct current internal resistance (DCIR) investigation would be also beneficial.

Reviewer 5:

The approach is to synthesize and develop new electrolyte additives that improve the cycling stability of LNMO/titanate and LNMO/C cells. Multi-layer pouch cells (MLPCs) are to be evaluated, and electrolyte properties (e.g., vapor pressure, transport properties, purity, and electrochemical stability) are to be measured. The approach seemed reasonable to the reviewer, although it was not clear what materials design strategy is being used (it appears entirely empirical).

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

It appeared to the reviewer that the project has been dramatically impacted by COVID-19, and this reviewer is certainly empathetic of this situation. So far, a few promising additives have been synthesized and evaluated, and their presence improves the performance over a baseline electrolyte in both LNMO/LTO and LMNO/C cells. A patent application and a couple manuscripts have been submitted. A USABC gap chart shows that the additives perform better in LNMO/LTO cells than LNMO/C cells. It will be interesting to see how further development can improve LNMO/C performance.

Reviewer 2:

Again, given the circumstances, the team made progress. The development of the new additives to enable HV-LMNO is ongoing and on a good path. The reviewer noted that it would be interesting to see if the progress of the improved formation protocol will also benefit the carbonaceous anodes part of the project.

Reviewer 3:

The reviewer stated that some performance targets have been met. However, the cycle life is still far from the target.

Reviewer 4:

According to the reviewer, some interesting progress, such as additive development, has been achieved. However, numerous challenges still exist to be overcome to meet the goals of this project. The technical challenges of LNMO in terms of cycle life and high-temperature performance may be potential challenges to the success of this project.

Reviewer 5:

It was difficult for the reviewer to see what was really achieved. The MLPC cycle life does not look good, and no noticeable improvement was presented. The project team claimed to have developed a procedure that formed more stable SEI, but no physical proof of stable SEI was not presented. No meaningful data are included for the Technical Achievements and Progress.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer found the collaborations among partners to be excellent.

Reviewer 2:

The University of Rhode Island (URI) is listed as a collaborator to synthesize and analyze electrolyte additives. According to the reviewer, URI’s involvement appears to be essential, particularly for the synthesis work.

Reviewer 3:

The reviewer remarked that URI synthesizes the electrolyte additive.

Reviewer 4:

For electrolyte characterization, the collaboration partner was well chosen, but the collaboration partner's contribution was not clear to the reviewer.

Reviewer 5:

The reviewer suggested that the team could benefit from some support from analytical groups deciphering some of the mechanisms behind the team's progress and maybe pointing the project into the right direction.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

Future work appeared to the reviewer to be reasonable, with directions focused on continuing additive synthesis and evaluation, particularly in HV-LNMO/carbon containing cells.

Reviewer 2:

The technical barriers for future are properly identified. However, the reviewer noted that options to address the challenges were not detailed.

Reviewer 3:

The reviewer suggested focusing only on electrolyte development. It is a right decision to focus on graphite anode instead of LTO anode for the test platform.

Reviewer 4:

There was a good plan on future research, but the reviewer said that more versatile testing would be helpful, such as resting at high temperature.

Reviewer 5:

Focusing on carbonaceous anodes will clearly speed up things with the deep knowledge already present in this field. It would be interesting to see an estimation of the costs of such a system including the novel electrolyte additives. The reviewer asked for the project team to please provide some information regarding toxicity and potential environmental concerns of the new additives.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that the objectives of this projects are targeted to reduce battery cost and increase battery life and energy density.

Reviewer 2:

The reviewer affirmed that development of HV electrolytes could enable higher energy density cathode materials, such as LNMO.

Reviewer 3:

The reviewer said that this project supports the overall DOE objectives by extending the cycle life of LIBs.

Reviewer 4:

The reviewer asserted that the project fully supports the DOE objectives

Reviewer 5:

Neither LNMO nor LTO can bring about a high energy density Li-ion cell. It was difficult for the reviewer to see what the focus of this project is among higher energy, fast charge, long cycle life, and low cost. Low cost is only meaningful when other cell performances are not compromised.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The resources for this project seemed appropriate to the reviewer.

Reviewer 2:

The reviewer indicated that resources seemed to be sufficient.

Reviewer 3:

Resources appeared sufficient to the reviewer for this project.

Reviewer 4:

It seemed to the reviewer that the resources are more than enough to achieve the goal.

Reviewer 5:

The electrode optimization part of the project would have benefited from working with a second university partner.

Presentation Number: bat442
Presentation Title: Behind-the-Meter-Storage (BTMS)–Overview and Update
Principal Investigator: Anthony Burrell (National Renewable Energy Laboratory)

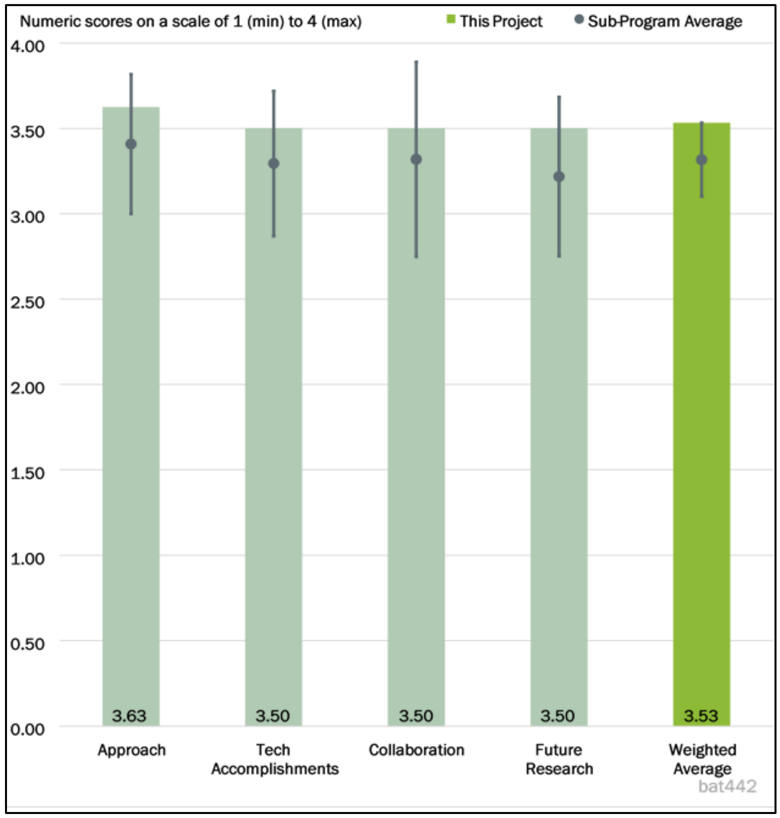


Figure 2-20 - Presentation Number: bat442 Presentation Title: Behind-the-Meter-Storage (BTMS)–Overview and Update Principal Investigator: Anthony Burrell (National Renewable Energy Laboratory)

Presenter

Anthony Burrell, National Renewable Energy Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 50% of reviewers felt that the resources were sufficient, 50% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

As the PI stated, this is a large and complex issue. According to the reviewer, the problem statement was well thought out, and the various factors that would determine success are well stated. This is ultimately a complex technical and financial analysis project, but all bases seem to be covered adequately.

Reviewer 2:

The reviewer said that the project has articulated well the problem of peak power demand and its impact on grid power. The need for fast charging is clearly identified. The project is identifying energy storage options specifically tailored for use at the gas station. The approach to use known anode materials like LTO for fast charging is credible and appropriate. Demonstration of fast charging capability is based on predictive modeling with accelerated life. The project is also adequately addressing the safety aspects of the LTO-based batteries.

Reviewer 3:

The reviewer indicated that the project is well designed. Inclusion of LTO systems and work are significant and non-trivial but was/is an excellent inclusion as the most relevant baseline/ideal. Enhanced explanation and background regarding the basis for this inclusion may help others understand its value.

Reviewer 4:

In Slide 2, the technical barriers for a fast-charging energy storage system were shown to be cost, performance and safety. However, the reviewer remarked that there is no preliminary cost estimate for such behind-the-meter storage (BTMS) or nor were the approaches to lowering the BTMS addressed.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

A surprising amount of data has been collected on the potential technologies under consideration to address the topic. As stated, there are more protocols to test for, but the reviewer was impressed with the amount of work so far.

Reviewer 2:

The reviewer noted that the project has demonstrated the preliminary feasibility of LTO-based batteries as a viable fast charging option. The initial experiments on optimization of LTO-based batteries appear promising. While the safety aspects have not been demonstrated, the project has outlined an excellent path forward to achieve safety. The modeling capabilities need to be explored extensively to address the safety of the batteries. The project is beginning to address the power electronics aspects of battery management system.

Reviewer 3:

The team has shown that LTO-based cells, specifically LTO-lithium manganese oxide (LMO), can meet the BTMS lifetime and cycle targets. The reviewer reported good progress on the performance of the LTO-based cells, but stated that cost and safety of BTMS have not been addressed.

Reviewer 4:

The reviewer found excellent technical accomplishments and progress to date. The contribution to knowledge in terms of economic implications may be an area that stands out a little for more enhancement.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

This is a large team effort. The reviewer had not yet gone through every other presentation associated with the project, but the emphasis on coordination in the overview presentation suggests that the coordination efforts are significant.

Reviewer 2:

Considering that the project is between VTO and three other DOE organizations, the reviewer assumed that collaboration and coordination across the project team is excellent. However, details illustrating the nature of collaboration or responsibility among national laboratory partners are not obvious from the review presentation, although this is also assumed to be excellent based on project activities and prior knowledge of specific national laboratories.

Reviewer 3:

The partners in the project (SNL, ANL, INL, PNNL) have outstanding battery technology development capabilities, and the reviewer asserted that their contributions have been partially responsible for the success of the project.

Reviewer 4:

The collaboration and coordination across the team were not clearly described even though data from project identification (ID) numbers BAT473, BAT492, and BAT472 were presented. The reviewer could not correlate the coordination between teams from their project IDs.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

Proposed future work appeared to be excellent to the reviewer. The intent to assess the impact of cell configuration (prismatic, pouch, and cylindrical) seems especially useful.

Reviewer 2:

The work plans seemed to the reviewer to be completely reasonable for the project.

Reviewer 3:

The reviewer found that the proposed future work is well thought out and appropriate. An integrated modeling approach that addresses safety, lifetime, and cell and pack design will help guide the project. Also, computational modeling tools can help guide the combination of no-Co chemistries and new electrolytes. Failure modes for various alternate chemistries need to be understood to address the safety aspects of the project.

Reviewer 4:

This reviewer commented that the plan for quarter (Q) 3 is to use the NREL EnStore model for evaluating the economic feasibility of BTMS using testing data from team members. However, the critical-material-free pouch cells (2 Ah) LTO/LMO will be prepared and tested using BTMS only in Q4. The reviewer suggested that NREL may be able to look into LTO/LMO cell data developed by Enersys and funded by DOE.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The development of a charging infrastructure is critical to the expanded deployment of EVs. The issue of addressing charge time at the charge station is much more complex than might be imagined, and this is a far-ranging analysis and project for methods to deal with this issue. The reviewer said that it is of course a given that the charge station dynamics must match the capabilities of the target EVs and so this is another area of coordination that will have to be considered along the way.

Reviewer 2:

According to the reviewer, fast charging is the key technology that will enable the building of charging infrastructure that will provide a "gas-like" station for charging an EV in less than 15 minutes.

Reviewer 3:

The reviewer stated that the project supports DOE's goal of low-cost, long-life stationary storage systems and fast charging capability.

Reviewer 4:

Although not directly relevant to EV performance objectives, the reviewer indicated that practicality and optimization of BTMS energy storage can impact viability and cost of more widespread EV adoption.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer commented that the FY 2021 funding of $2.4 million is adequate for the BTMS proof-of-concept demonstration.

Reviewer 2:

Resources are sufficient for the moment. As the project moves to execution, the reviewer warned that a re-evaluation of resources will need to occur.

Reviewer 3:

The reviewer noted that resources devoted to the project seem to potentially be insufficient for the relevant project time period and intended future work.

Reviewer 4:

There is significant experimental effort (e.g., assessment of no-Co chemistries and development of new electrolytes) and design activities in the proposed future work. The reviewer was not sure if all the proposed work can be completed within the remaining budget. The reviewer was not privy to the detailed budget breakdown and could not provide more comments here.

Presentation Number: bat456
Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Anode Structures that Enhance Fast Charge
Principal Investigator: Andrew Jansen (Argonne National Laboratory)

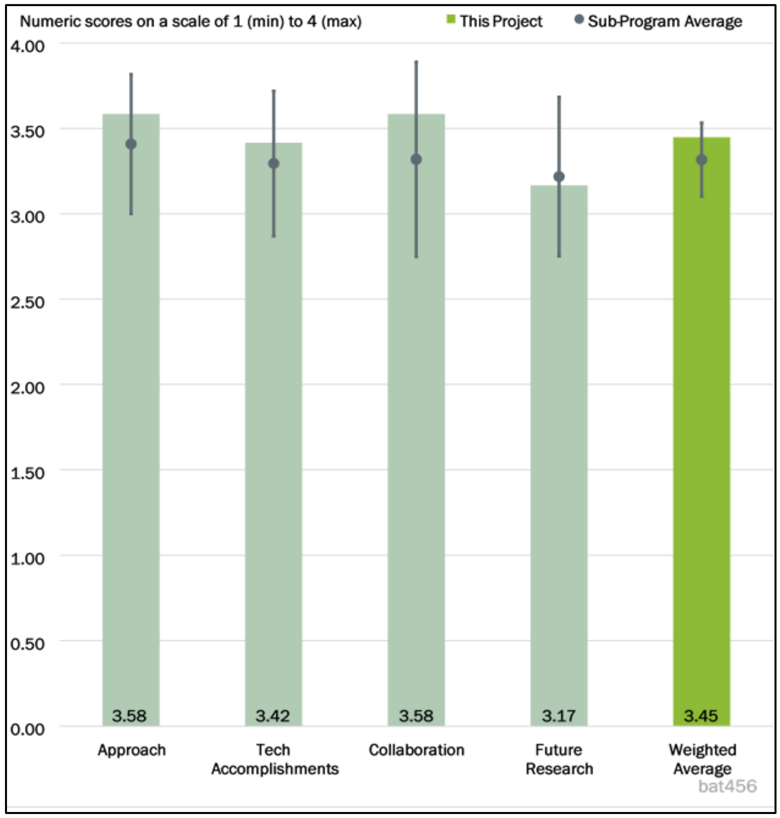


Figure 2-21 - Presentation Number: bat456 Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Anode Structures that Enhance Fast Charge Principal Investigator: Andrew Jansen (Argonne National Laboratory)

Presenter

Andrew Jansen, Argonne National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 17% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer observed that this project is responsible for developing and fabricating physical electrodes and cells for examination within the larger extreme fast-charging (XFC) program. This project (the Electrode and Electrolyte Thrust) provides materials and cells to other portions of the XFC program for testing and characterization and then creates iterative designs to minimize the possibility of Li plating under fast-charge conditions.

Reviewer 2:

The reviewer commented that the project is a highly focused and well-planned approach to improve upon the issues stemming from fast charging, such as anode compositions, structures, electrolyte compositions, formation process, among others, and combines both experimental studies and modeling work. Interestingly, the reviewer noticed that the PI mentions thick anodes and lower temperature as factors for Li plating but does not mention state of charge [SOC] or voltage.

Reviewer 3:

The reviewer remarked that fast charging is a hard problem and requires a broad approach that will address electrode and electrolyte design.

Reviewer 4:

The reviewer asserted that the project clearly addresses the barriers of an electrode design for a fast-charge application. The proposed and developed methods are sound and well designed. One area for improvement would be to focus more on the volumetric energy density effect of the approaches on the anode level and to provide an indication how this would affect the overall cell parameters, i.e., volumetric and gravimetric energy density on the cell level.

Reviewer 5:

This is excellent research effort combining modeling, electrode fabrication, and testing using modeling outputs. It was not clear to the reviewer how the cost of the fast-charging cells was calculated (Slide 19). The reviewer asked whether the cost was just based on the energy output, what the cost was of manufacturing these special electrode architectures, and if the cost of using special solvents and additives had been considered.

The negative-positive (N/P) ratio is about 1.14 (Slide 18), which might be slightly on the higher end of what industry uses and this might help mitigate Li plating due to extra anode capacity. For the future work, the reviewer questioned whether the team had considered balancing N/P ratio such that there is no extra anode capacity and taking irreversible capacity out of the equation through prelithiation. The reviewer asked if doing this might allow for a better benchmarking of the anode materials and architectures.

Reviewer 6:

The approach used combined modeling and experimental methods, which the reviewer applauded. As volumetric energy density is still a key metric for automotive use, it would have perhaps been better to examine an approach that maintains (or improves) energy density while simultaneously achieving fast-charging goals. The use of electrolyte channels within the electrodes themselves is most likely a nonstarter on account of the volumetric energy density requirements.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer observed that the team has achieved successive pouch cell builds using iterative materials and designs to create improved cells for XFC applications. Over the subsequent builds, the binder and carbon additive content have been reduced to increase energy density and charge rate. The team has so far produced a "Hero" cell as an intermediate milestone cell on the way to final cell deliverables scheduled for the end of FY 2021. Additionally, the team appeared to complete the milestones on time thus far.

Reviewer 2:

The reviewer said that progress was shown both in designing the electrode and optimizing electrolyte. The underlying mechanism of performance improvement was also detailed, which enables a foundation for future work.

Reviewer 3:

There has been excellent progress to date and definitely a lot of interesting experiments under a variety of conditions. It would be really important to the reviewer for the team to do some repeatability and reproducibility studies for the "Hero" and next generation cell builds.

Reviewer 4:

The project appeared to the reviewer to be well structured and managed. Progress is quantified with standard measurements. It would have been good to see how other typical aging characteristics (calendar life) are affected by any changes in the electrolyte or by using smaller particle sizes.

Reviewer 5:

The reviewer found that considerable excellent results have been obtained thus far both experimentally and via modeling. There is nice agreement between modeling and experimental data for loading studies, and demonstration via modeling that graded anode shows improved Li plating characteristics., The beneficial effect of pore architecture and transport and electrolyte studies all add to a very robust database of excellent results that will aid in improved understanding and mitigation of Li plating issue. The B26 electrolyte does indicate good improvement also.

While conceptually it may be elegant, the reviewer was not sure freeze tape casting is a commercially attractive process. Also, while the structures of the proprietary electrolytes are not given, the reviewer saw one with a nitrile functional group. Nitriles are usually not stable as cathodes. Also, the reviewer wanted to know how the PI ensured that the electrodes were fully wetted and that no gas-bubbles were trapped.

Reviewer 6:

The progress is good; however, further investigation into the combination of the formation process and the electrode design toward the fast-charge capability of the electrode would be appreciated. It also seemed to the reviewer that the fluoroethylene carbonate (FEC) component of the electrolyte could be consumed irreversibly over time, it would be great if the team could investigate the FEC content after more than 1,000 cycles.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

It was a pleasure for the reviewer to observe how the team members actively participated and answered questions in the chat room and referenced each other's work; clearly, there is full transparency, engagement, and good communication among team members.

Reviewer 2:

The role of the individual organizations was detailed nicely, and it was very apparent to the reviewer that the project benefitted immensely from the complementary strengths of the individual organizations.

Reviewer 3:

The reviewer found the project team and collaboration to be excellent.

Reviewer 4:

This reviewer reported that collaboration extends across multiple institutions.

Reviewer 5:

The XFC program is a collaboration between six national laboratories and multiple universities. This thrust (the electrode and electrolyte) provides materials and cells to other collaborations within the team, including providing cells to INL for testing as well as Stanford Linear Accelerator Center (SLAC) for understanding of lithium plating. Although the existing collaborations are strong, the reviewer suggested getting additional collaboration and input from industrial partners to ensure approach, cell design, and details are using best practices that have been determined commercially.

Reviewer 6:

The reviewer suggested that a collaboration with a team that could investigate the evolving temperature rise within the cell during the fastcharge would be helpful to gain further insights.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The presenter proposes to continue to develop new anode electrode technologies including bi-layer anode cell design in order to improve fast-charge performance. The team also plans to investigate higher loading cells, including 4 mAh/cm^2 loading electrodes. The reviewer agreed that higher loading cell investigation will be critical to translating this development to the industrial level for EV applications. Additionally, the presenter mentioned a focus on investigating formation conditions and advanced electrolyte investigations into the impact for XFC performance. The reviewer agreed that these are important variables for future research and looks forward to the results.

Reviewer 2:

According to the reviewer, proposed future work is a logical extension of prior work.

Reviewer 3:

The reviewer appreciated the focus on graded electrodes, formation conditions (especially at higher temperatures), and stable electrolytes. Some of the work, while novel (pore formers and increased salt content) might not be practically attractive from manufacturing or cost points of view. The reviewer suggested that the team keeps this aspect in mind while pursuing these activities.

Reviewer 4:

The reviewer indicated that future research is well thought out. It would be great to see a design-of-experiment approach after the “Hero” materials and conditions are defined.

Reviewer 5:

Again, there is a need for both improved volumetric energy density and decreased cost while simultaneously achieving fast-charging times. The reviewer commented that future work would be better focused on Si in the anode, allowing higher temperature operation and/or magnetic ordering of graphite.

Reviewer 6:

It would be great if the team could focus more on cell level parameters, the heat evolution in the electrode during the fast-charge and investigate the practicability of their approaches for industrialization and mass production. Furthermore, the reviewer asked the team to please consider contamination due to the use of pore formers in the proposed research.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that this is an extremely relevant project since fast charging is of utmost concern to vehicle users.

Reviewer 2:

The reviewer commented that fast charging is believed to accelerate adoption of the e-mobility and potentially reduce the size of the batteries without contributing to range anxiety.

Reviewer 3:

The reviewer indicated that fast charge is one of key challenges to enable broader commercialization of LIB technology.

Reviewer 4:

The reviewer noted that this project does support the overall DOE objective of accelerating EV adoption and reducing cell costs by providing fast-charging capabilities.

Reviewer 5:

Fast charging is a key barrier to the widespread adoption of EVs, according to the reviewer.

Reviewer 6:

The reviewer found that this project supports the overall DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

According to the reviewer, this is a key issue with cells and batteries, and it would be nice to have a higher amount of resources allocated for this project.

Reviewer 2:

The reviewer remarked that resources are sufficient to achieve the stated milestones in a timely fashion.

Reviewer 3:

Resources are sufficient for the scope of the project.

Reviewer 4:

The reviewer said there are sufficient resources.

Reviewer 5:

The reviewer noted that there is a great team working on this project.

Reviewer 6:

Sufficient resources were noted by this reviewer.

Presentation Number: bat457
Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Methods for the Detection and Quantification of Lithium Plating
Principal Investigator: Johanna Nelson-Weker (SLAC)

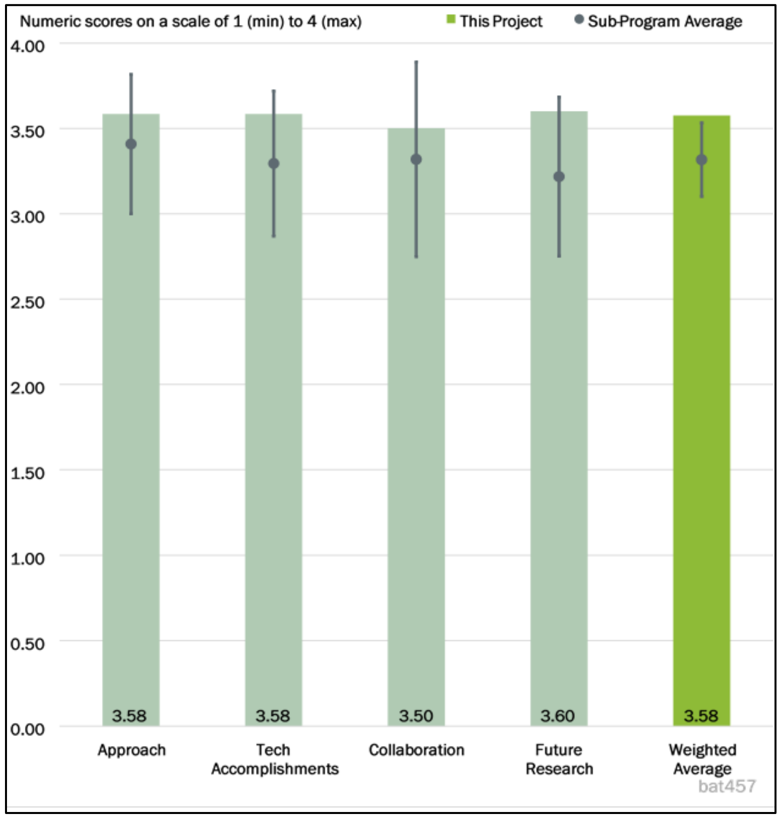


Figure 2-22 - Presentation Number: bat457 Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Methods for the Detection and Quantification of Lithium Plating Principal Investigator: Johanna Nelson-Weker (SLAC)

Presenter

Johanna Nelson-Weker, SLAC

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 17% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that the objectives of this project are extremely challenging, and the ability to think outside the box is critical to finding the right methodology. The milestones reflect well the questions that need to be asked and answered to progress toward finding a solution.

Reviewer 2:

The reviewer called the approach in general outstanding. The inclusion of and approach with a particular Coulombic efficiency (CE) study, thermal wave investigations, and comprehension of pressure effects appear to be very effective choices.

Reviewer 3:

According to the reviewer, this is a well-organized research project that tackles the very important issue of Li detection and its quantification utilizing a diverse array of techniques and modeling.

Reviewer 4:

The reviewer commented that the project examines a variety of different Li detection techniques to understand where the Li is trapped or lost during cycling, when Li plating occurs, and whether it creates irreversible damage contributing to cell failure. These examinations are toward the goal of achieving an XFC technology. It is part of a larger project to understand how to best develop XFC technology.

Reviewer 5:

The project is well designed and addresses the key questions of the challenge. The reviewer would highly appreciate benchmarking with existing technologies, especially considering the vast partner network and knowledge already established in the national laboratories.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer indicated that this is a critical area, and tangible practical progress is challenging. However, the tight focus in the project on key aspects and accomplishments to date are excellent.

Reviewer 2:

The technical plan is comprehensive, and the reviewer stated it is easy to follow what is being done and why. Regarding Slide 15, the reviewer asked that the PI elaborate on what N/P ratio is, explain why it had been selected to be much less than 1, and what the rationale for the experiment is.

Reviewer 3:

The reviewer remarked that very impressive progress has been achieved in identifying the onset and quantity of Li plating. This is a challenging task, but the use of electrochemical and mechanical diagnostic tools has given excellent insights into the usefulness of these techniques to reliably predict and quantify Li plating.

Given the fact that the industry needs inexpensive, robust, and fast methodologies to minimize and manage this issue, the reviewer stated that the data do not show that aside from CE-related studies the others will pass muster in this regard.

Reviewer 4:

The team has made significant progress in the detection and quantification of Li in different electrochemical setups. The methods are in part novel and innovative. The reviewer would have appreciated a review and comparison with existing methods on academic and commercial scale, e.g., a comparison with state-of-the-art digital pressure foils used commonly for pouch cell pressure testing, and a stronger emphasis on the difference between reversible and irreversible Li deposition and plating. One open question would be also the quantification and the modeling of a recovery effect. The reviewer asked if and how irreversibly plated and deposited Li can be recovered. Another point would be the influence of heterogeneity on the recovery effect; specifically, how structured electrodes, proposed in other projects, would influence the Li deposition.

Reviewer 5:

The presenter has examined multiple Li-detection techniques to build a picture on where the Li is trapped during cycling. Of note, the presenter described the use of mass spectrometry (MS) and titration to get quantitative values for the trapped Li inventory in an electrode structure and was able to deconvolute the location and cause of the Li inventory by the molecule created via MS. However, it is the reviewer's opinion that plated Li metal in the presence of graphite or partially lithiated graphite is not thermodynamic, and the resulting phases may vary as a function of time as the cell relaxes. Therefore, it is critical that variables such as time from charge cutoff to characterization be carefully controlled in order to increase the precision of results.

The presenter also showed XPS depth profiling results. The reviewer said it would have been good to understand the standard deviation of the individual components to understand whether the differences in calculated concentrations were statistically significant.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer praised the team for having members who can very effectively complement each other's strengths, and this project clearly benefitted from that, given the nature of all the experiments and simulation.

Reviewer 2:

According to the reviewer, the teams involved in XCEL demonstrated outstanding collaborative spirit and engagement that is reflected in the progress shown.

Reviewer 3:

The reviewer remarked that the team seems to be well connected in a strong partner network.

Reviewer 4:

The reviewer stated that collaboration appears to be very effective and activity area responsibilities are illustrated usefully.

Reviewer 5:

This presentation is part of a larger project that is a collaboration between six different national laboratories and multiple universities. The reviewer believed it may be helpful to have some industry collaborations as well to ensure that the cell design and chemistry considerations are utilizing best practices.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer asserted that the proposed future work will focus on connecting Li- plating results with understanding more about their impact on electrochemical performance.

Reviewer 2:

The reviewer stated that the project will end in September 2021. The remaining tasks are well designed to fulfill the goal of the project.

Reviewer 3:

The reviewer called the understanding of the challenges excellent but cautioned that it is important to include statistical analyses.

Reviewer 4:

The proposed future work looked excellent to the reviewer. If there is any suggestion for improvement, perhaps slightly less focus on X-ray photoelectron spectroscopy (XPS) studies and more on other activities that may lead to most tangible results.

Reviewer 5:

The future research listed (e.g., how much Li plating is acceptable and how to estimate it) is keenly focused on understanding, quantifying, and predicting Li plating. However, the reviewer asserted that the laser-sharp focus should be on the development of very reliable (robust), fast, and low-cost methodologies that can be deployed in real applications preferably under dynamic conditions, too. Also, the work should also focus on tools that could be used both in metal can and pouch-type of cells. According to the reviewer, some techniques such as pressure may never be sensitive enough to be used as a diagnostic tool.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer observed that fast charge is and will continue to be a critical area for further work, development, and understanding in support of overall DOE objectives and will serve alongside energy density as a key interdependent metric in the more widespread adoption of EVs.

Reviewer 2:

The reviewer affirmed that this project is focused on decreasing battery charging time via development of XFC technology, which is a known objective of the DOE. Understanding current limitations to XFC technology is critical to overcoming challenges and enabling industrialization.

Reviewer 3:

The reviewer indicated that this is a highly relevant issue since Li plating affects both life and potentially safety of the batteries.

Reviewer 4:

XCEL is extremely relevant to the industry current and future technologies, according to the reviewer.

Reviewer 5:

Overall, the project supports the DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

Given the nature and urgency of this issue, the reviewer opined that the funding level should be increased.

Reviewer 2:

Resources devoted to the project seemed sufficient to the reviewer and relatively appropriate within the overall DOE portfolio in the related time period.

Reviewer 3:

According to the reviewer, resources are sufficient for the project.

Reviewer 4:

The reviewer indicated that the team seems to have sufficient resources for the work provided.

Reviewer 5:

The reviewer said the resources are just right.

Presentation Number: bat459
Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Heat-Generation Concerns Associated with Extreme Fast Charging
Principal Investigator: Matthew Keyser (National Renewable Energy Laboratory)

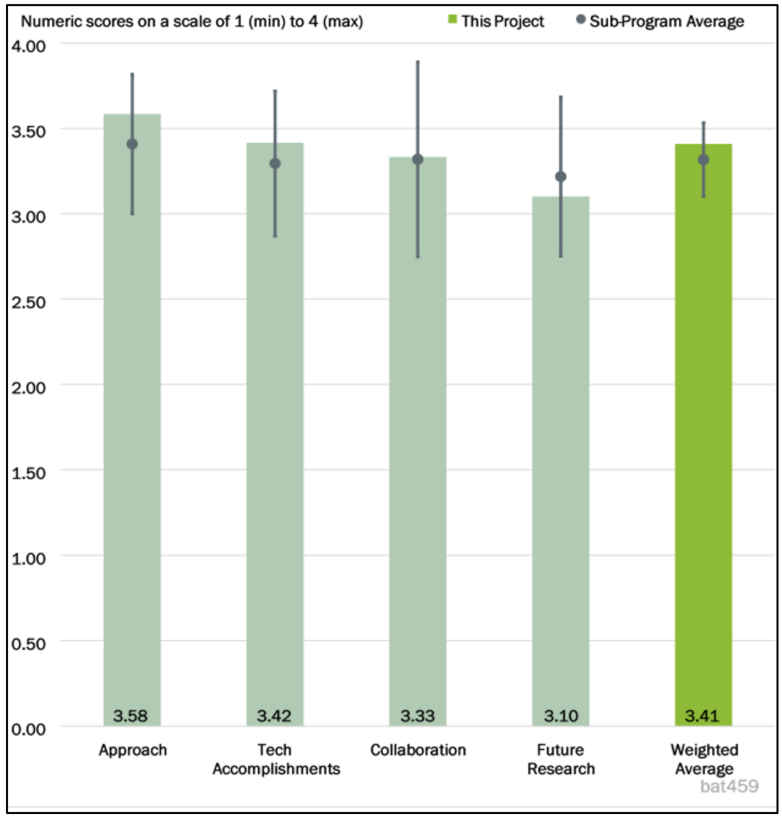


Figure 2-23 - Presentation Number: bat459 Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Heat-Generation Concerns Associated with Extreme Fast Charging Principal Investigator: Matthew Keyser (National Renewable Energy Laboratory)

Presenter

Matthew Keyser, National Renewable Energy Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer commented that the approach toward the issue is outstanding. Developing techniques that can detect temperature increase and correlate that with modeling makes it very relevant. The developed model can be used to run several conditions using multiple variables.

Reviewer 2:

The reviewer observed that this is an overlooked problem from a fundamental perspective and was very glad to see the national laboratories addressing it. The project objectives were clearly communicated, and the project seems on track. The combination of modeling and experiments is well coordinated.

Reviewer 3:

This reviewer remarked that considering what is going on inside the battery cell (by temperature measurement) in the battery model development will lead to insightful information about how the battery is functionating including ideas about capacity loss with battery use.

Reviewer 4:

Thermal modeling during fast charge is very common, however, the reviewer asserted that the novel part of this is the spatial resolution, which may provide insight into novel ways to combat thermal issues during fast charge. It is nice to see an approach that can operate on a practical cell size instead of being limited to small geometries.

Reviewer 5:

The reviewer pointed out that the project is strongly focused on the impact of heat generation within the battery cell during fast charging while considering lifetime, costs, performance, and safety. However, especially while measuring and understanding temperature inhomogeneity within the battery cells is solidly investigated using both empiric and three-dimensional (3-D) modeling simulations, a direct connection to cost targets was not clearly addressed. It would have been helpful to see the estimated cost reductions targeted or at least understand the requirements that need to be changed to reach costs targets. Also, it would have been helpful to understand the approach of how the resulting adaptive protocols can be incorporated into real-life EV applications.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The progress on experimental methods and validated models has been good; milestones have been accomplished. The project is now moving on to making improvements in reducing heat generation and improving thermal transport. The reviewer stated that it was great to see the linking of understanding leading to ideas for improvement and asked if the model(s) can be generalized and made available to the public.

Reviewer 2:

The reviewer indicated that showing the effect of high temperature charging followed by lowering temperature before discharge begins is good data and can help industry design their product inducing charger. Can this feature be built-in with the application of LIB?

Reviewer 3:

The approach appeared strong to the reviewer, but without a robust set of technical results, it was difficult for the reviewer to evaluate. The data results, such as on Slide 8, are not novel, and it would beneficial if the project team could model ways to improve heterogeneity challenges instead of only showing a well-known baseline case.

Reviewer 4:

The project met all the objectives set when it started, but the reviewer said that there is still some more work needed to fit the model to real data.

Reviewer 5:

As indicated by the PI, the project is on track, having reached all previous milestones so far. While there are still a lot of remaining challenges and barriers (see Slide 20), the data collected and the progress so far are excellent. Still, the approach of how the adaptive protocols are planned to be applied to test packs, for example, has not been outlined clearly. Also, the amount of contribution of each individual measurement method toward the adaptive protocol as well as interdependencies and interconnections of the methods used were not very clear to the reviewer.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

According to the reviewer, there is outstanding collaboration and coordination across project teams.

Reviewer 2:

The collaboration between all contributing partners seemed to the reviewer to be in perfect alignment.

Reviewer 3:

The deep dive into fast charge appeared to the reviewer to be well coordinated, and varying approaches were designated to the labs with the best experience in the technology. This project, with more focus on modeling of larger cells, seems perfect for NREL.

Reviewer 4:

This reviewer reported that many DOE labs are working together with two leading universities in the United States.

Reviewer 5:

Although the cross-lab team is listed, the Results slides do not reflect inputs from anyone outside of NREL and LBNL. Future work may drive toward more collaboration, but it was not clear to the reviewer that all listed contributors had key contributions in this update.

*Question 4: **Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.***

Reviewer 1:

Making accurate temperature measurements as part of the proposed research was described as a good idea by this reviewer.

Reviewer 2:

The reviewer reported that the project is coming to an end in September 2021. However, the proposed future work warrants another project to continue this research because there is still a lot more work that is relevant to the industry.

Reviewer 3:

Proposed future work made a lot of sense to the reviewer, who was glad to see the work extended to the module, pack, and charging station. If the cell thermal issues can be fixed, then a problem should not just be moved to the next component.

Reviewer 4:

It seemed to the reviewer that the challenges and barriers of the project are well addressed. Nevertheless, the project plan still seems to have more open questions than questions answered. Also, a clear red line why specific measurement methods are chosen and a pathway and/or explanation how methods are complementing each other has not been clearly shown.

Reviewer 5:

The reviewer remarked that the method of trying to manage fast charge with thermal controls as a system is an approach industry will not want to adopt. System designs are all about efficiency in space, weight, and cost; if the coolant system must be orientated in a way to reduce volume usage or requires oversizing to manage fast-charge events, the costs are likely too great for industry to overcome. The project team should focus their attention on the final project of 3-D architectures as this is a solution that has more viability for highly efficient, commercial battery packs.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

This project is more relevant because the reviewer said that heat generated in direct-current fast charging (DCFC) is the most important roadblock that needs to be solved or improved to make EVs more comparable to internal combustion engine (ICE) vehicles.

Reviewer 2:

According to the reviewer, widespread adoption of EVs in the United States requires more consumer acceptance. Implementation of fast- charge technology reduces range anxiety and opens the market to many consumers who do not have a place to charge their vehicle at home.

Reviewer 3:

The reviewer stated that fast charge is a key barrier to passenger EVs. The project supports improving this metric to enable a larger market.

Reviewer 4:

The reviewer remarked that the project addresses challenges that are highly relevant in all fast-charging R&D topics.

Reviewer 5:

This reviewer commented that getting technology behind reliable and durable battery operation is going to be quite useful and relevant to industry.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

The reviewer opined that the objectives can be met with the resources allocated to this project.

Reviewer 2:

The funds provided for the project seemed to the reviewer to be sufficiently used.

Reviewer 3:

The reviewer asserted that the national laboratories have the right resources, skills, and technologies to accomplish the goals of this project.

Reviewer 4:

This reviewer described the team led by Matt as very well resourced and supported by universities and various DOE labs.

Reviewer 5:

It was difficult for the reviewer to evaluate a $5.6 million spend in about 20 slides. Work appears to be heavy on modeling and lighter on lab work, which may indicate that the budget is slightly excessive, but the complete story may not be in these slides.

Presentation Number: bat461
Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Quantifying Heterogeneities/Degradation During Fast Charge
Principal Investigator: Andrew Colclasure (National Renewable Energy Laboratory)

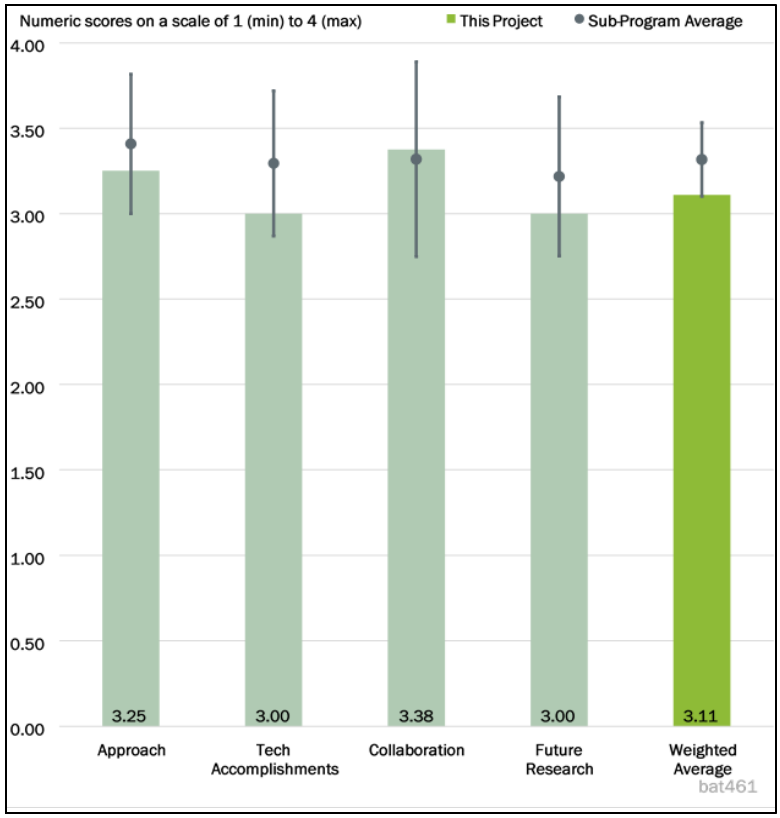


Figure 2-24 - Presentation Number: bat461 Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Quantifying Heterogeneities/Degradation During Fast Charge Principal Investigator: Andrew Colclasure (National Renewable Energy Laboratory)

Presenter

Andrew Colclasure, National Renewable Energy Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 50% of reviewers felt that the resources were sufficient, 25% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

This project is very complementary to the other projects in this portfolio. The combination of experimental methods and models is a key strength of the work. The focus on practical issues such as wetting is important to the industry. The reviewer’s only concern is that conclusions may be unique to the cell size, design, and methods studied in the project. The reviewer thought that the lithium nucleation and plating model is quite interesting and would like to see it extended and validated with different types of cells.

Reviewer 2:

The reviewer asserted that understanding heterogeneity in electrodes and how it affects Li plating is very important to DCFC. In that case, the research has employed several techniques to quantify these effects, but it is still only confirmed in ideal conditions. How this research affects cells in real-world conditions has to be a priority to make it more relevant.

Reviewer 3:

The project team has used significant funding and high-powered instrumentation to provide small- scale resolution of in operando and ex situ measurements of the lithium plating process. While the data are quite elaborate, the results do not appear to the reviewer to be novel compared to what has been known prior to this work. The work is not well controlled: some tests are at 4.4 V, others with just 4.1 V. Timing details are not discussed yet the presentation shows wetting timing is a critical area to understand. Some tests are done at 9C, some at 1C, and others at 6C. The approach needs to be more systematic, and care needs to be taken to ensure the data collected from one subsection can be used to better understand another. The PI highlights material selection, such as electrolyte and graphite, as being critical but gives little insight in this presentation into the specific details of their designs. NMC 532/graphite can have a wide range of particle shapes, sizes, load weights, electrolytes, etc.

*Question 2: **Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.***

Reviewer 1:

The results met the objectives set at the start of the project, but the reviewer stated that the impact of the results is not profound. There are some excellent accomplishments in getting more understanding of the phenomenon, but there is lot more work that needs to be done.

Reviewer 2:

Project milestones appeared to the reviewer to be on track. This project does have a number of different techniques and approaches, which can seem disconnected. For example, high-speed XRD depth profiling was done on highly oriented pyrolytic graphite (HOPG), and the reviewer asked if this were a relevant material. The next slide is on graphite nanoplatelets, which may be more relevant. The reviewer did think that the work is fine— just that the presentation needed a key take-away on each slide. It looks like tools are in place, but now need to be used in a consistent fashion to determine the causes of the heterogeneities. Regarding electrolyte wetting, the reviewer wanted to know if this is a big industry problem or if the project is solving a problem to which there is already an answer.

Reviewer 3:

This work has found a few interesting areas of how Li plating occurs in preferential ways. Most of the findings are confirmation of old approaches, such as the comparison of Dahn's in-situ XRD to the PI's methods. For the amount of funding in this project, the reviewer asserted that there should be more novel accomplishments and less confirmation of previous work. After more than 3 years into this project, the reviewer expected to see more novel findings by this time or robust methods that other researchers could apply to their systems.

*Question 3: **Collaboration and Coordination Across Project Team.***

Reviewer 1:

The reviewer said that there is good collaboration and coordination across the project teams.

Reviewer 2:

According to the reviewer, there is good coordination and teamwork for the entire fast-charge effort.

Reviewer 3:

As the reviewer previously stated, the partners are not well coordinated, and there are differences in test parameters that do not allow collaborative data analysis. The discussion in Future Work on the "Hero" cell may be a good chance to align parameters. It was also very difficult for the reviewer to tell what work in the presentation is within this project and what is previous work. For example, Brigham Young University (BYU) is not listed on the front page but has an extensive data section slide and a logo in the conclusion.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer reported that the program is ending in September 2021, but there is still a lot more to be done to answer the question of why there is Li plating in DCFC. This requires a follow-up project to answer these questions.

Reviewer 2:

The work on the Hero cell is a good project. The rest of the proposed work appears to confirm methods already done. Given the extensive publication list in the presentation list, the reviewer would have expected most methods to be confirmed at this time so it is not necessary to complete this work. It would be beneficial if the project team were to look at the requirements for some fast-charge projects and provide insight into key challenges to meet the fast-charge and life portions of those requirements.

Reviewer 3:

The reviewer wanted to know if the tools are adequate to answer the question on the underlying cause of heterogeneities. The reviewer was not sure from the presentation and asked if there were a Plan B. This is a very challenging problem, and the reviewer thought that more advanced characterization techniques will be needed to fully understand all the issues. The reviewer was not sure this can be completed by the end of the project.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that fast charge is a key area for DOE, and this project focuses on analysis of fast-charge failures.

Reviewer 2:

Understanding what causes Li plating and how that can be managed are very important to get DCFC more applicable, according to the reviewer.

Reviewer 3:

The reviewer asserted that widespread adoption of EVs requires consumer acceptance. Fast charge addresses two key concerns: range anxiety and the ability to charge EVs for those that cannot do it at home.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer said that the project has sufficient resources to complete the project.

Reviewer 2:

The reviewer did not think there is enough time left in this project to fully understand the issues. This really is not the fault of the investigators as it is a big challenge.

Reviewer 3:

The reviewer stated that DOE's goal in funding battery projects should be on the impact they make toward domestic electrification and use of batteries. This work appears to be an opportunity for the project team to publish articles and does not clearly provide a benefit to the domestic market that is in line with the spending of this project. Although fundamental research is removed from the final good, it is still important that the work focuses on an end point and is not simply there to create publications.

Presentation Number: bat462
Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Aging and the Role of Fast-Charge Protocol
Principal Investigator: Eric Dufek (Idaho National Laboratory)

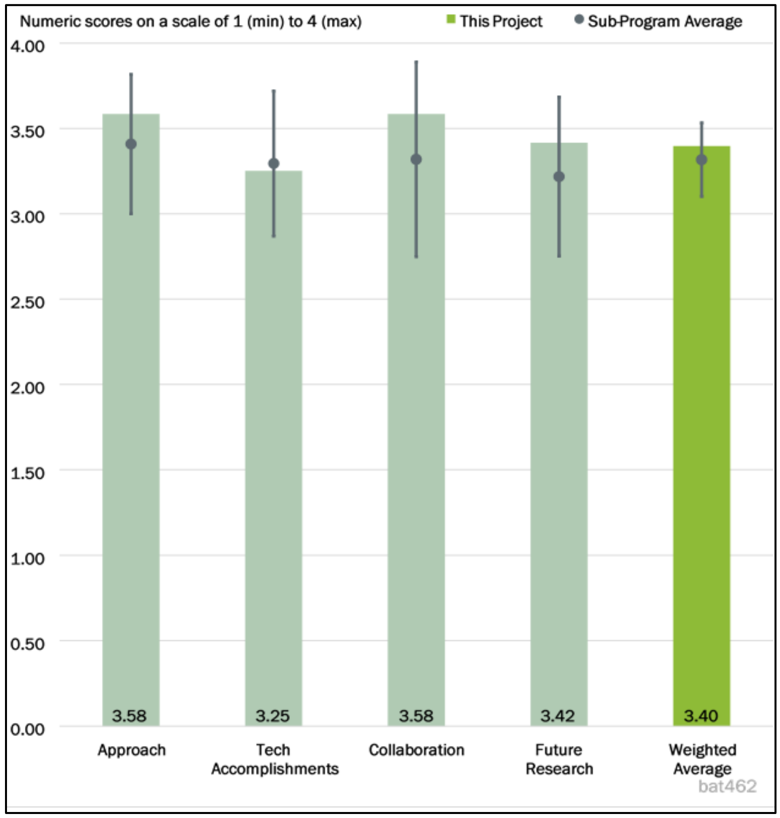


Figure 2-25 - Presentation Number: bat462 Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Aging and the Role of Fast-Charge Protocol Principal Investigator: Eric Dufek (Idaho National Laboratory)

Presenter

Eric Dufek, Idaho National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer observed that the teams within the XCEL project do great work defining workstreams, and each team complements the other without duplicating the efforts. The project uses the skills and knowledge of the team members to meet research objectives.

The teams might start considering validation work using larger cell format with industry partners.

There is excellent use of the decision-tree framework.

Reviewer 2:

The reviewer found the approach in general to be outstanding. The focus on thermal ramp and on ramp protocols is particularly effective.

Reviewer 3:

The reviewer asserted that development of new charging protocols and methods to analyze degradation mechanism under fast charge is very important for commercialization of LIBs.

Reviewer 4:

The reviewer noted that the approach taken combines experiment with modeling. The system-level accessible parameters (current profile and temperature) were examined for their influence on improving lifetime under fast-charging conditions.

Reviewer 5:

The approach appeared well thought out to the reviewer, who said that shows a clear relationship between charge protocols and Li plating. It would be great to incorporate this approach together with electrode-level improvements to the anode. The reviewer also remarked that it is necessary to track the cell temperature as well as Li plating. A fast-charge approach without consideration of temperature will not be practical for EV applications due to safety and long-term degradation concerns.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

According to the reviewer, this is a critical area and tangible practical progress is challenging. However, tight focus in the project on key aspects and accomplishments to date are excellent.

Reviewer 2:

The reviewer remarked that work done to date meets overall project objectives for the selected cell design. It is also important to demonstrate the applicability of the framework to advanced battery systems using increased Si content in the anode.

Reviewer 3:

The reviewer commented that the ability to influence Li plating on the anode by charge protocol development is clearly shown. Good results showing improved charge acceptance at high C-rates.

It is clear that temperature has a large impact on the system so the reviewer wanted to know how the cell temperature impacts degradation. In addition to anode mechanical issues shown in the presentation, this could cause degradation issues during long-term cycling.

In Slide 8, the reviewer asked that the lack of changes in the electrolyte be confirmed under lean-electrolyte conditions (as would be used in a commercial EV cell).

Reviewer 4:

While some aspects are excellent, it was still unclear to the reviewer what the actual practical impact is of the technical accomplishments of this project.

Reviewer 5:

The reviewer mentioned that a reference electrode cell in combination with a numerical model was used to identify a charging profile that improved lifetime. This is good, of course. A way to modify this over life or for different temperatures is also needed. The next logical step in this development was not carried out. Therefore, the results are mostly confined to this study and not transferable to the field at large.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

There is excellent collaboration and coordination, and the reviewer offered kudos to the project team. The reviewer was impressed watching the chat conversations, which demonstrated true engagement, support, and knowledge.

Reviewer 2:

The reviewer affirmed that collaborator impact and contributions are clear and well stated, and the reference to electrolyte from other projects indicates good collaboration.

Reviewer 3:

According to the reviewer, collaboration appears to be very effective and activity area responsibilities are illustrated usefully.

Reviewer 4:

The reviewer found the team to be very competent.

Reviewer 5:

The reviewer believed that the collaboration could have been better than it appears in the presentation. In the future, it would be good to show on each slide how the different institutions are contributing.

Question 4: ***Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.***

Reviewer 1:

Proposed future work looked excellent to the reviewer, and the intention to explore mid-range SOC in particular should be especially relevant to the real world.

Reviewer 2:

The reviewer said that the proposed future work plan is sound.

Reviewer 3:

The reviewer noted that the project definitely needs to be continued.

Reviewer 4:

As mentioned by the presenter, adaptive charge protocols are essential for EV-relevant fast-charge systems. In the reviewer's view, the ability to react to different degradation profiles and user profiles will be necessary as the system continues to be developed. To examine calendar life effects and long-term degradation, it could be helpful to test some "Hero" cells using a lower fast-charge duty cycle (i.e., fast-charge every other cycle of one-third of the cycles).

Reviewer 5:

The reviewer responded affirmatively and said that adaptive protocols are necessary. But, there is no mention on how and what approach could be used. The reviewer expected there to have already been action on this front.

Question 5: ***Relevance—Does this project support the overall DOE objectives? Why or why not?***

Reviewer 1:

The reviewer asserted that fast charge is and will continue to be a critical area for continued work, development, and understanding in support of overall DOE objectives and will serve alongside energy density as a key interdependent metric in the more widespread adoption of EVs.

Reviewer 2:

The reviewer opined that understanding aging under fast-charge conditions is very relevant to DOE objectives.

Reviewer 3:

According to the reviewer, fast-charging protocols are very important to overcome the charging challenge.

Reviewer 4:

The reviewer stated that Industry needs high-energy and high-power cells for multiple applications.

Reviewer 5:

The reviewer affirmed that fast charge is key for customer adoption of xEVs. Addressing Li plating will help mitigate key failure modes and safety issues of fast-charging EVs.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted that resources are sufficient.

Reviewer 2:

Resources devoted to the project seemed sufficient to the reviewer and relatively appropriate within the overall DOE portfolio in the related time period.

Reviewer 3:

The reviewer recommended that the team work with an OEM partner.

Reviewer 4:

The reviewer would like to have seen more results from this part of the project, as mentioned earlier.

Reviewer 5:

The reviewer said that there seems to be the ability to fully characterize the system between all the partners.

Presentation Number: bat463
Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Effects of Extreme Fast Charging on Lithium-Ion Battery Cathode
Principal Investigator: Tanvir Tanim (Idaho National Laboratory)

Presenter

Tanvir Tanim, Idaho National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

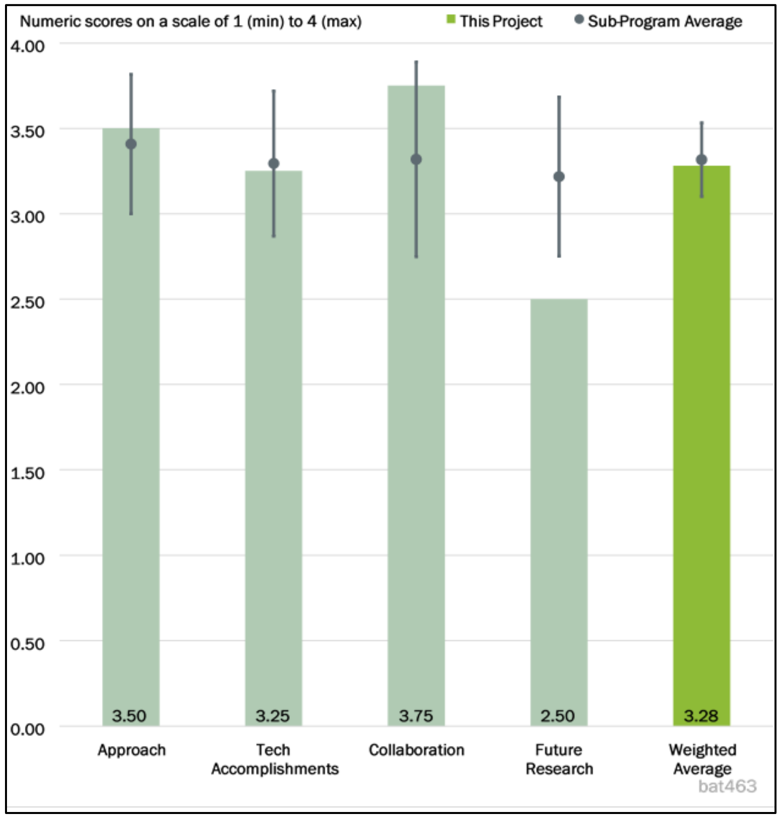


Figure 2-26 - Presentation Number: bat463 Presentation Title: eXtreme Fast Charge Cell Evaluation of Lithium-Ion Batteries (XCEL)–Effects of Extreme Fast Charging on Lithium-Ion Battery Cathode Principal Investigator: Tanvir Tanim (Idaho National Laboratory)

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer called the approach to understanding cathode degradation due to DCFC outstanding. The experiments and the corresponding simulation work made the project well designed.

Reviewer 2:

This reviewer explained that understanding the impact of high-rate charging is an excellent idea as material properties are being understood by the project team under extreme fast charging. Effecting battery fast charging and understanding its chemistry by analytical modeling will help solve many problems including application variability as the model could capture such variations by parametric analysis. Therefore, the reviewer asserted that analytical modeling is quite critical to problem solving.

Reviewer 3:

The reviewer remarked that the project is well defined, with approaches to overcoming degradation and failure modes on the cathode side that occur during extreme fast charging.

Reviewer 4:

There is very detailed analysis using scanning electron microscopy (SEM) methods. Use of software to gain more insight into data was refreshing for the reviewer to see instead of moving to high-powered instruments.

The reviewer had a concern with the data on Slide 8, which states that cracking of particles does not lead to loss in performance, yet the entire presentation is focused on eliminating cracking and characterizing it. The reviewer suspected the conclusion of Slide 8 was made after the other work had started, but the future work should gear more toward what Slide 8 has found as a non-issue instead of developing solutions to the observation.

The reviewer said that using such a small cell (0.019 Ah) for this study may lead to misleading results. The cell's area is quite large relative to its capacity; this work should continue with larger cells of at least 5 Ah of capacity to better characterize gradients in processes, temperatures, etc., under a length scale that better represents the end use and could highlight more common issues.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer indicated that significant work related to various elements affected by fast charging have been investigated by the project team.

Reviewer 2:

According to the reviewer, the DOE work done to understand the mechanism of particle cracking and to correlate it with modeling was a good accomplishment. The project met all the objectives set at the start. However, there is still more work needed to understand how this failure can be mitigated and controlled to meet consumer objectives.

Reviewer 3:

As the PI indicated, the technical progress has been impacted by the COVID-19 pandemic. The approach of the project of considering identification of effects of XFC on cathodes seems to be well chosen. Nevertheless, it was not clear to the reviewer if the advancements identified will have a solution directly on material level and, if yes, what the approach on material level would be (e.g., choice of different production methods, additional particle or electrode coatings, and impact of particle-size distribution).

Reviewer 4:

Much of the technical work here has already been well understood prior to this study. The reviewer stated that it is nice to see a single study comparing NMC811 and NMC532, but the results are not novel. The in situ spatial XRD data are interesting, but the project team should have provided more analysis and observations on this. The true accomplishment of this work is the advanced image processing, which can be applicable across a wide range of materials and not exclusive to lithium-ion.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer stated that there was outstanding collaboration and coordination across all project members.

Reviewer 2:

The reviewer commented that the collaborations across labs and universities involved seems to be working extremely well.

Reviewer 3:

The reviewer noted many DOE labs working together on this extremely important research, which is very relevant to U.S. industries.

Reviewer 4:

It was clear to the reviewer that INL and ANL have a strong relationship on this project. It is great to see the academic support from University of Ulm on the imaging data processing, but it would be nice if the team could focus that work at a domestic lab instead of an international source. This would help strengthen the talent base for battery researchers, which is extremely limited today.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

This reviewer observed an excellent plan on many issues such as completing understanding of NMC811 aging mechanisms; planned work on cathode-related issues; quantitative methods for quantifying particle cracking and correlating with electrochemical understanding on the spatial distribution of utilization and cracking, etc. This is a great plan for future research and will allow the project team to know battery degradation caused by fast charging.

Reviewer 2:

The reviewer questioned the focus on cracking when the project team has concluded on Slide 8 that this is not causing a loss in performance. It would be useful to use the conclusions to generate future work to answer known concerns.

Reviewer 3:

The project is ending in September 2021, but the reviewer suggested that there is still a lot more future work needed as a follow up to the findings in the project.

Reviewer 4:

In the reviewer's opinion, there are still more challenges to be approached to generate full understanding of the cathode-aging mechanism in connection with XFC.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer noted that this helps support the movement to nickel-rich cathodes, which are an enabler for lower cost EV cells.

Reviewer 2:

The reviewer asserted that the project is most relevant to the industry to make DCFC a more useful application.

Reviewer 3:

Understanding the internal details of batteries is very relevant research from this reviewer's perspective.

Reviewer 4:

The project supports the targets to identify the aging and degradation mechanisms for cathodes during XFC. However, the pathway where the contribution of these results will be allocated (charging protocols, material development, and electrode production) was not crystal clear to the reviewer.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

According to the reviewer, the project had sufficient resources to accomplish the tasks set at the start of the project.

Reviewer 2:

This reviewer stated that the team is well resourced and the PI gets help form many DOE labs.

Reviewer 3:

The resources appeared to the reviewer to be sufficient for this project.

Reviewer 4:

These projects show a bundled cost, which made it hard for the reviewer to gauge each subsections true cost and value. The reviewer suggested that the budget for the core research in these slides be more easily stated than a blank $5.6 million for all of XCel.

Presentation Number: bat464
Presentation Title: ReCell–Direct Cathode Recycling: Material Separation and Preparation
Principal Investigator: Albert Lipson (Argonne National Laboratory)

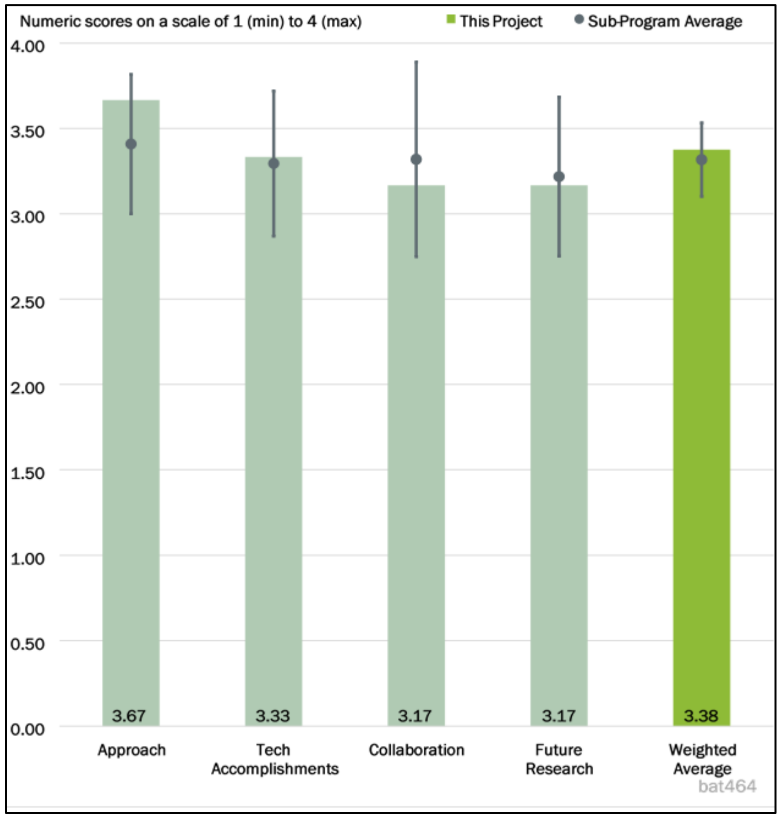


Figure 2-27 - Presentation Number: bat464 Presentation Title: ReCell–Direct Cathode Recycling: Material Separation and Preparation Principal Investigator: Albert Lipson (Argonne National Laboratory)

Presenter

Albert Lipson, Argonne National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer commented that the technical barriers and milestones are clearly discussed and elegantly addressed in the initial slides.

Reviewer 2:

It is good to see the United States investing in battery recycling. The reviewer was interested in understanding how the approaches investigated here are better or different from those developed by others (e.g., Umicore). Maybe there is no need to re-invent the wheel, just make the wheel better or cheaper. However, the reviewer appreciated the variety of approaches investigated for all the components and asked if cost effectiveness is being taken into consideration on all of them.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer remarked that the project has shown different approaches toward recycling cathode and anode materials from scrap batteries. Significant progress has been accomplished by showing recovery of more than 90% for NMC cathode materials.

Reviewer 2:

The processes for the cathode recovery would seem to be the highest value, so the reviewer was glad to see that those were successfully developed; electrochemical results look okay so far. The reviewer asked whether the other components are worth it. The project is 90% complete and tried a lot of methods. The reviewer did not see enough data on the recovered materials to be convinced that the selected methods are good enough to scale up. It may exist but was not adequately shown in the presentation.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The team appeared to the reviewer to be large, thus- allowing a lot of different methods to be investigated.

Reviewer 2:

It was not clear to the reviewer about the collaboration structure in this project.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer asserted that the project has elegantly planned the scale-up process to recover critical materials at high yield and high purity. Pathways for the scale-up process have been identified, and that will improve the probability of success for this project.

Reviewer 2:

The reviewer thought that the proposed future work needs to include a lot more testing and characterization of the recovered and recycled materials.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that successful recycling of EV batteries materials at reasonable cost will provide a clear path for reducing the cost of EV batteries to less than $60/kWh.

Reviewer 2:

According to the reviewer, the United States does not have an adequate secure supply of raw materials for EV batteries. A low-cost recycling program will supplement our access to the supply chain.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer indicated that the remaining resources are sufficient for the scale-up stage of the project.

Reviewer 2:

The project is almost complete and appeared to the reviewer to have achieved its milestones.

Presentation Number: bat465
Presentation Title: ReCell–Direct Cathode Recycling: Relithiation and Upcycling
Principal Investigator: Jack Vaughey (Argonne National Laboratory)

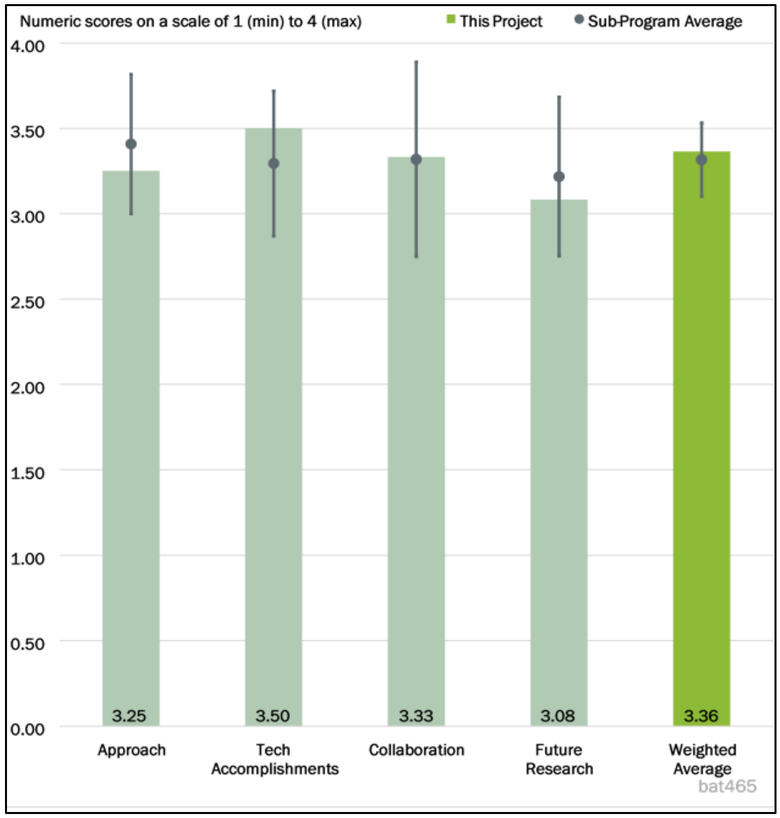


Figure 2-28 - Presentation Number: bat465 Presentation Title: ReCell–Direct Cathode Recycling: Relithiation and Upcycling Principal Investigator: Jack Vaughey (Argonne National Laboratory)

Presenter

Jack Vaughey, Argonne National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 17% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer stated that the program is an important contribution to understanding how Li-ion battery cell electrodes can be recycled in a cost-effective way. The program anticipates that the desired composition of NMC will change with time and three methods for upgrading has been demonstrated. Three methods of lithiation were also demonstrated through the program. The reviewer further commented that it will be interesting to find out more performance data as the program continues to see the viability of the materials produced.

Reviewer 2:

This reviewer opined that the research team took a very good approach by assessing technical feasibility of the multiple processes for relithiation of NCM based cathode materials. It would be great to deep dive some of the promising processes by running additional performance/life tests.

Reviewer 3:

The reviewer observed a wide range of recycling issues being identified and solved in this work. The team is responsive to data and future data correlates to lab results well. The concern with this work is the overuse of EverBatt to guide research. The EverBatt and other national laboratory models are cumbersome and tend to have incorrect inputs of the true state of the art. Given how early stage some of this research is, the reviewer suggested that the team should focus on understanding processes and chemistry first instead of asking a model to predict solvents or boundary conditions for its work. Having a cost-effective process is important but if the chemistry simply will not work understanding cost up front at this level of detail is not important.

Reviewer 4:

The reviewer indicated that this is a surprisingly ambitious take on the reuse of cathode active material from recovered electric vehicle batteries. The evaluation of various aspects of regeneration of the material is very complex and this program has laid out some good program goals. This reviewer suspected that there are more "real world" challenges that exist than can be expressed in the program right now, but this early-stage evaluation is well thought out.

Reviewer 5:

Although the project is well-designed and feasible for the intended tasks, the reviewer noted that the basic focus on rejuvenation recycling does not seem practical.

Reviewer 6:

The reviewer remarked that the project takes a comprehensive approach to address the many possible avenues of reviving spent LIB materials—from hydrothermal, thermal, to ionothermal and electrochemical. The knowledge obtained is invaluable for such an emerging technological sector.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer reported that the program has demonstrated thermal, hydrothermal, and ionothermal methods to perform lithiation and upcycling. It is early to tell the success based on the limited data available on performance, which likely results from the reduced amount of lab time because of COVID-19. However, it is good that different methods were pursued to eventually compare technical performance and cost-effectiveness of the various methods.

Reviewer 2:

This reviewer observed great accomplishment. Processes for relithiation and upcycling were thoroughly investigated, and the team was provided with information on limiting steps for some processes and suggestions to mitigate technical constraints.

Reviewer 3:

The reviewer commented that clear challenges in lithium dissolution and sintering have been identified by the team. Some of this chemistry, such as EtOH as a solvent, is well known from early NMC work. It was unclear to this reviewer whether old research was used or not, but at times the processes and chemistry feel complex and may benefit from a literature research to find some simpler starting points. However, it is clear that as challenges are found, the team is working the problem instead of focusing on characterization.

Reviewer 4:

This reviewer noted good progress on demonstrating progress on the two main technical thrusts of the program. Although it is stated that the program will not include the second use evaluation of the materials, the reviewer hoped that this is being addressed somewhere in the system as it seems critical to setting ultimate targets for success.

Reviewer 5:

The reviewer remarked that the technical accomplishments and progress are perhaps excellent from a scientific perspective, but the potential feasibility for practical implementation or at least the thinking behind it does not seem to have been demonstrated or conveyed.

Reviewer 6:

This reviewer described accomplishments and progress as satisfactory. The efficiency and feasibility of recycling and upcycling are designed effectively to face the new cathode materials that is a dynamic factor in the manufacturing and recycling of LIBs. The team displayed outstanding expertise in conducting the technical tasks.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

It appeared to this reviewer that the project team worked together very effectively in challenging times.

Reviewer 2:

This reviewer observed good collaborations among the entities, experts in each area for battery recycling process research. Expertise includes electrode material science, physical and electrochemical analysis, material recycling processes, battery manufacturing for validation tests, etc.

Reviewer 3:

The reviewer noted a multi-institutional team that closely collaborated on the various approaches. The different fronts seemed to be highly synchronized.

Reviewer 4:

The reviewer stated that this is a large collaboration team, and further commented that the program presented results as a unified set of results, which suggests a good coordination effort.

Reviewer 5:

Although collaboration and coordination are assumed to be good or better, the reviewer indicated that it was difficult to understand collaboration or coordination across the team from the presentation or other info.

Reviewer 6:

The reviewer could not tell who provided what based on provided slides and noted that the work appears to be all ANL.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer described future work outlined as appropriate to assess the outcome of the recycling methods developed. The multiple path routes should help to mitigate risk. A little more detail about any decision points would be helpful to effectively spend the resources.

Reviewer 2:

The reviewer stated that further technical evaluation is great, but as proposed by presenter, economic feasibility study of each process will be good addition to this excellent work.

Reviewer 3:

Scale-up and industrial discussions are a great first step, but this reviewer disagreed with using EverBat at this time because the chemistry needs to be more stabilized to make modeling meaningful.

Reviewer 4:

The reviewer indicated that the initial technical goals of the program are well thought out and the future work is reflective of the current program effort. As a practical matter, this program will require notably more infrastructure development than is being addressed by this program.

Reviewer 5:

Given the work done to date, proposed future work seemed appropriate to this reviewer. Any further work to elucidate true rate capability or temperature dependence in relevant full cells versus relevant baseline full cells may be illuminating.

Reviewer 6:

In future research, this reviewer suggested that the emphasis should be placed on these scalable approaches—hydrothermal, thermal—while approaches involving the use of solvents or ionic liquids should be de-emphasized. The electrochemical, in particular, should be gradually phased out. The LIBs to be recycled in the future are in the approximate scale of MWh to GWh. Therefore, these non-sustainable approaches should be abandoned; otherwise, they will only make the process highly costly and cause more environmental and landfill problems rather than solving them.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

This reviewer asserted that battery recycling is and will continue to be of key and ever-growing importance in supporting overall DOE objectives.

Reviewer 2:

The reviewer stated that this is right on target to meet DOE objectives of lowering the cost of batteries to increase market penetration.

Reviewer 3:

The reviewer remarked that this research significantly impacts on DOE’s objective of EV battery cost reduction.

Reviewer 4:

The reviewer described this project as highly necessary and should be prioritized, considering that electrification of transportation is an irreversible pathway, while consumer and other sectors’ spent LIBs are already starting to pile up.

Reviewer 5:

This reviewer indicated that recycling of active materials, particularly cathode materials, is critical to the long-term infrastructure of electric vehicles. This is a surprisingly ambitious approach to that issue and, if successful, could be a significant contribution to EV infrastructure.

Reviewer 6:

Domestic supply chain improvements and reduction in cell cost was reported by this reviewer. The authors should start to identify partners to commercialize the process before cathode manufacturing starts to build in North America so the recycling aspect can be integrated into the plant layouts.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

The reviewer stated that resources devoted to the project seem sufficient and relatively appropriate within the overall DOE portfolio in the related time period.

Reviewer 2:

Based on the work reported in this year, the reviewer noted a good research team with the right expertise was formed generating very interesting data for last year.

Reviewer 3:

The appropriate amount of funding was available to carry out this work from this reviewer's perspective.

Reviewer 4:

This reviewer described resources as sufficient for now, and added that success at this level will lead to a much higher demand for resources.

Reviewer 5:

The allocation of resources seems reasonable, but this reviewer suggested that the approaches—those involving solvents/ILs and electrochemical—should be de-emphasized and phased out for long-term scalable consideration.

Reviewer 6:

This reviewer could not tell if all approximately $14 million is spent within just these 20 slides or what else is included. $580,000 per slide is a very expensive price of research and this is all the data that this reviewer has from which to evaluate.

Presentation Number: bat467
Presentation Title: ReCell–Battery Design for Recycling
Principal Investigator: Jianlin Li (Oak Ridge National Laboratory)

Presenter

Jianlin Li, Oak Ridge National Laboratory

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 57% of reviewers felt that the resources were sufficient, 29% of reviewers felt that the resources were insufficient, 14% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

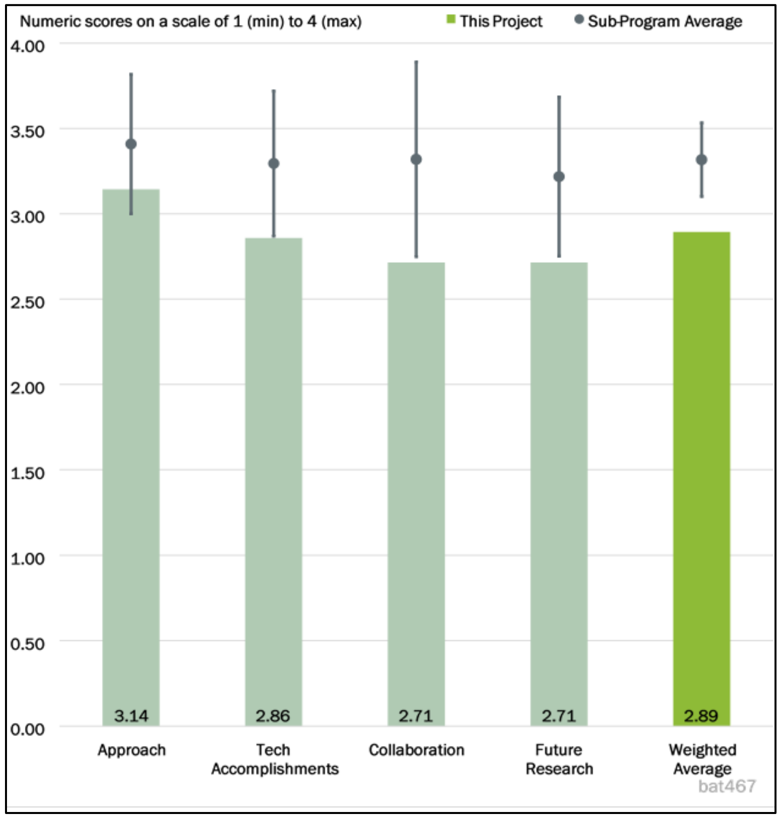


Figure 2-29 - Presentation Number: bat467 Presentation Title: ReCell–Battery Design for Recycling Principal Investigator: Jianlin Li (Oak Ridge National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer indicated that the investigator presented a well-researched effort. It seems that if funding is continued so as to support the work, a viable solution will result which enables efficient recycle of battery systems.

Reviewer 2:

The reviewer stated that this portion of the ReCell project focuses on battery design for recycling. Specifically, the project team is focused on new cell designs that are specifically aimed at rejuvenation/reuse in recycled applications. This reviewer further added that the project team is focused on new cell designs to allow more easy removal of SEI components and other items.

Reviewer 3:

The reviewer noted that cell design is critical for ease of recycling.

Reviewer 4:

It seemed to this reviewer that there should be more focus on understanding why the refreshing is not working before optimizing the ability to refresh. For example, it may be that this is not possible under pressure.

Reviewer 5:

The project is a good concept from this reviewer's perspective. It looks like it needs a lot more lab time to define what type of battery aging can be restored with fresh electrolyte. The reviewer explained that short project timeline limits flush and restoring electrolyte to 100-80% cycling. Electrolyte restoration may be more effective if battery was aged more. Refresh seems to benefit about 50 cycles or 2 months of real-world cycling. The reviewer hoped that the team would get a restore of 300 cycles (or an annual vehicle service) and suggested that it should explore if a reflush at later stage—70%, 60% 50%--would yield more restoration and life. This is worth it to go back to, even if the results would not be available by the end of the project. The reviewer added that the project has some minor lab barriers to solve such as the flow tube and connections.

Reviewer 6:

The reviewer observed a novel design to make it possible to remove SEI and adding fresh electrolyte to recover some capacity for spent cells. However, as well known, there are many factors leading to capacity fading of a lithium-ion battery or cell—Li-ion inventory loss due to continuous SEI growth, impedance increase, electrolyte depletion, etc. Without compensating the Li-ion inventory loss, the recovered capacity is limited. Any economic analysis to justify the approach? How does the added ports impact safety and performance? How practical is the approach for industry?

Reviewer 7:

The reviewer explained that the concept of rinsing the cell to rejuvenate it and extend the life is a novel approach that could contribute greatly to ReCell objectives. This approach also has the advantage that it could apply across the diversity of battery chemistries being developed.

The reviewer indicated that the presentation was generally poor and confusing in both the oral presentation and the slides. The project design and planning needs substantial improvement, and the technical objectives are unclear. Is the objective to remove SEI—some components and if so, which components—or is the objective to relithiate the cathode? How does this rejuvenation work and how does the project team expect it to work? The reviewer observed no systematic approach evident as to optimizing flushing procedures and details of the procedures were omitted. This seems to be a rather preliminary exploratory study from a few months of work. Technical targets were not provided. The reviewer further stated that this project is a poor execution of what would seem to be a great idea.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that progress to date seems good given the experimental nature of this research.

Reviewer 2:

This reviewer noted that the researcher demonstrated the viable potential of success for the technology via prototype development.

Reviewer 3:

The reviewer described the concept as well defined. The fresh electrolyte flush shows a short-lived effect, which proves the concept is good. However, more work is needed to get a longer effect and restoration of more capacity per flush, and the reviewer asserted that this is going to be a lot of hard work and will require new ideas. Tough to put a timeline on this as it requires an inventive leap. Even if the inventive leap is not realized immediately, a stable system for having a way to flush & replenish a battery flush would be a success as it would leave a path for the superior flush/restore to be effective when it arrives.

Reviewer 4:

Good results were noted by this reviewer, but there are still major challenges around reusing of recycled materials. Also, it was not clear to the reviewer if proposed cell designs are practical.

Reviewer 5:

The reviewer remarked that some capacity is recovered after rinse and fresh electrolyte addition, but the capacity fading becomes faster. Considering the long cycling life of EV batteries, i.e., greater than 1000 cycles, what is the target for cycling life after rinse and fresh electrolyte addition? Although relithiating spent cathode is mentioned in project goal, no related work was mentioned in the following slides. Is it feasible to combine electrolyte rinse and addition with cathode relithiation?

Reviewer 6:

Technical progress seemed sketchy to this reviewer, who added that it was hard to judge because very little information is shared on the procedures and parameters for the rinsing and new electrolyte addition. Performance indicators are not clearly presented; so, comparison of results to technical targets is not provided. How much cycle life improvement is targeted? How long does the rinsing and new electrolyte add take versus what target times?

The reviewer indicated that it is reported that the cells designed for rinsing and electrolyte refill “failed after a few days due to electrolyte loss.” This is not adequate for reasonable testing of how much the cycle life can be extended. The reviewer explained that this type of mechanical development should have been successful given great resources and fabrication facilities available at ORNL, and more effort should have been expended on this. Furthermore, multiple cell designs should have been developed. This cell design is a critical component of this project.

Apparently, there was an effort to speed up the flow for rinsing and electrolyte replenishment by changing the anode active material graphite (although this reviewer did not see quantitative results on how that worked and, again, there was no technical objective). That does not seem like a great approach because it could have deleterious effects on performance or cycle life. The reviewer reported that no information on this was provided. There should be other approaches to increasing the flow independent of the active material composition including design of flow channels in the cell and perhaps microflow channels in the electrodes themselves.

This reviewer was not impressed by the technical accomplishments and progress in this project toward the novel and promising approach of the project.

Reviewer 7:

The reviewer commented that over the past year, the project moved from experiments in coin cells and into practical pouch cells. The presenter demonstrated various electrolyte washing techniques that were investigated with little success, and also highlighted challenges with modifying pouch cell fabrication with ports to try to investigate washing. It was also mentioned that the project team has not yet accomplished successful data acquisition.

Overall, much progress is needed in order to execute on the promising approach of this thrust. The reviewer believed that the approach and underlying idea behind “design for recycling” is very powerful, although it has been poorly executed in this project thus far. The reviewer can imagine alternative development pathways to improve the technical project progress, such as including active lithium inventory components into the “electrolyte wash” to compensate for lithium losses to the SEI in the existing project. The reviewer could also imagine another project focused on developing and integrating small amounts of inactive electrode additives that could be decomposed to allow for easier recycling/recovery of active materials, or other projects that could more broadly advance the "design for recycling" agenda.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

It was very clear to this reviewer that the Recell project is well defined and working on many avenues. The collaboration across the projects is clear.

Reviewer 2:

A very competent team was observed by this reviewer.

Reviewer 3:

This reviewer commented that team efforts were used to accomplish work to-date.

Reviewer 4:

The reviewer noted a great team with excellent collaborations, though an industrial partner may make the team better.

Reviewer 5:

Although this was not really mentioned, the reviewer stated that it seems like progress would be difficult without it.

Reviewer 6:

This reviewer remarked that the presenter did not mention or highlight any particular collaborations with other project team members. Some of these interactions may have occurred, although they were not highlighted beyond the boilerplate "collaboration and acknowledgements" slide.

Reviewer 7:

The reviewer indicated that there was no specific mention of any collaboration or coordination with other members of the impressive ReCell team. This project needed help in several areas; so, collaboration in the future is highly encouraged.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The proposed future work plan was described as sound by this reviewer.

Reviewer 2:

Proposed future research is appropriate for this approach from the reviewer's perspective. Sealing of the added ports are key for safety and performance, especially after rinse and fresh electrolyte addition.

Reviewer 3:

The reviewer stated that work should be continued and proposed future efforts will continue to evolve viable recycle solutions.

Reviewer 4:

As this reviewer mentioned previously and because refreshing does not seem to be providing long-term benefits, it seems that there is a risk that this cannot be done in this form. Before continuing with doing a better job of adding ports, the reviewer suggested that it would make sense to mitigate this risk by understanding how to improve refresh performance to match the coin cell results.

Reviewer 5:

This reviewer recognized the need for a leak-free system of flushing. Without breaking this barrier, there is a hole in the project, and the reviewer offered suggestions to the author—need to design a cell network (even if it is only two cells) to better understand limits of flushing and compare front cell to second cell. The rest looked good to this reviewer.

Reviewer 6:

The reviewer commented that the presenter briefly discussed continuing to work to improve sealing of the pouch cells with the ports, although the initial data from the adjacent project has failed to demonstrate that this approach will lead to improved performance or achieve the targeted results. The presenter acknowledged that these R&D cells contain excess electrolyte at the beginning, and are therefore less likely to be improved with the electrolyte flush. The reviewer respectfully believed that the future work needs to be reconsidered.

Reviewer 7:

This reviewer explained that the proposed future work is limited to finding improved sealants for the flow cell and further investigating alternative electrode microstructures for electrodes to improve flow. The reviewer's impression was that making the flow cell work will require more than a more effective sealant and that a more comprehensive effort should be made on the mechanical design of the flow channel. This reviewer also thought that the approach of redesigning the porosity of the electrodes is risky and undesirable because that will probably affect the performance and/or cycle life, most likely having an adverse effect on both.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer remarked that enabling increased battery life would increase the viability of energy storage.

Reviewer 2:

Because these resources are mined outside of the US, this reviewer indicated that recycling makes extra sense. This is an insane amount of material, too, and toxic waste dumps popping up all over the world are not needed. Anything that can be done to extend the life of the battery is even more useful than recycling.

Reviewer 3:

The reviewer stated yes, this project supports overall DOE objectives. The life of pouch cells is a big challenge in EV application; investigating the capacity loss and finding solutions are very necessary.

Reviewer 4:

The reviewer asserted that cell designs accounting for the need to eventually recycle batteries are relevant to DOE objectives.

Reviewer 5:

DOE has a focus on battery development and viable recycle of developed technology, and the reviewer stated that this work serves to support this overarching goal.

Reviewer 6:

The reviewer indicated that yes, in theory, this project supports the DOE objective by improving the ability to recycle battery materials, which can lead to reduced costs for batteries and therefore accelerate EV adoption and reduce GHG emissions and global warming.

Reviewer 7:

The reviewer described this project concept as excellent with great promise to extend the cycle life of LIB cells with a relatively simple procedures at least in principle. Although this reviewer was unimpressed with the planning and execution of this project, the project start and funding level were unknown to the reviewer. If this was an exploratory preliminary study of several man-months, the reviewer thought it showed enough promise that this deserves a serious effort with good planning.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer stated that work was adequately funded.

Reviewer 2:

Sufficient resources were observed by this reviewer.

Reviewer 3:

This reviewer described a very strong team and suggested that some support from industrial partner may be very helpful.

Reviewer 4:

Although this was not described in detail, the reviewer noted that the level of effort seems adequate given the discussed scope.

Reviewer 5:

This reviewer was not clear on the resources or time allotted for this project. The result was not impressive and inadequate resources may be the reason.

Reviewer 6:

Although resources for this particular thrust were not separated from the larger program, it did not seem to this reviewer that many resources would be required to complete these results. Subsequently, the reviewer hoped that resources had been diverted to more promising approaches.

Reviewer 7:

This reviewer indicated that there are a lot of aspects of this project that need a deeper dive. Unfortunately, the timeline and resource are not allowing that in-depth look. Given the data, the project team needs some answers to go in the right direction and the IPA wash yielding greater recovery needs some understanding.

Presentation Number: bat470
Presentation Title: Process R&D Using Supercritical Fluid Reactors
Principal Investigator: Youngho Shin (Argonne National Laboratory)

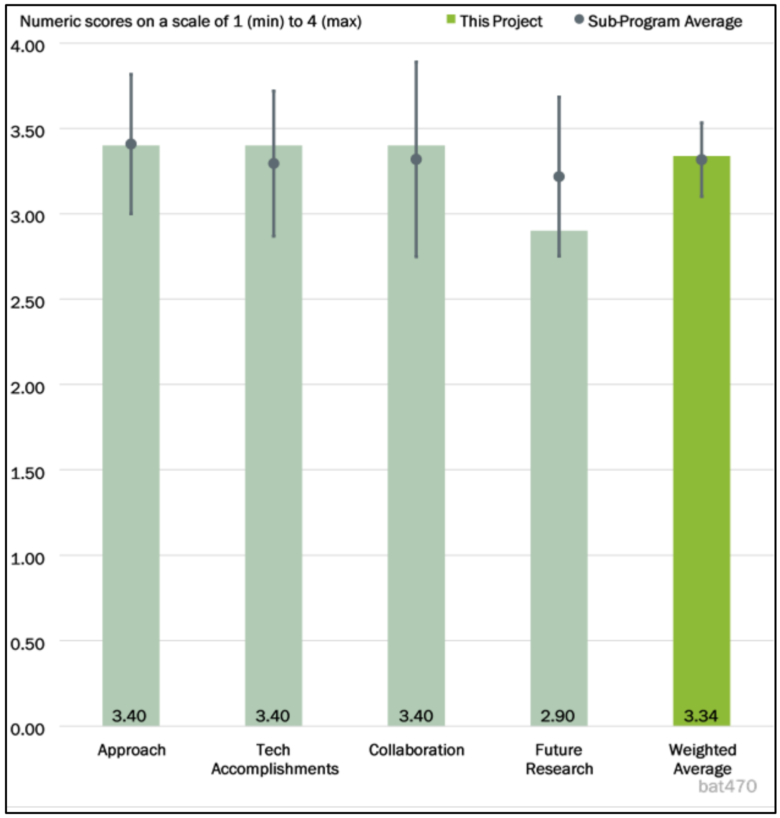


Figure 2-30 - Presentation Number: bat470 Presentation Title: Process R&D Using Supercritical Fluid Reactors Principal Investigator: Youngho Shin (Argonne National Laboratory)

Presenter

Youngho Shin, Argonne National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

This reviewer commented that the research team has successfully developed a hydro-solvothermal process for synthesizing single crystal NMC particles of controlled size. The particles have no grain boundaries and are more robust than polycrystalline cathode particles. The density of single crystal particles is also higher than polycrystalline powders. The reviewer indicated that this is a nice approach to making a better performing cathode.

Reviewer 2:

The reported that the project aims at one of the important aspects of synthesis—producing high quality single crystal high-Ni NMC. The technical barriers in the process development with the new HYST method has been well captured. Additionally, incorporation dopants, which is another important aspect of long-cycle and stable electrochemical performance, has been addressed as well.

Reviewer 3:

The reviewer stated that the goal of this project was to produce electrode materials through a hydrothermal synthesis approach, which the PI did effectively. Details regarding the approach with respect to the equipment were not given, but the results clearly show viable powders have been produced.

Reviewer 4:

This reviewer noted a reasonable approach that is appropriate for the materials being studied. The process approach produces unique battery materials in a flexible manner that is critical to fundamental studies. If continued beyond September 2021, the reviewer expressed interest in seeing an analysis on the feasibility of this process to realistically scale to larger quantities. If this project does produce materials that are of interest for commercialization or scale-up beyond 40 grams, it is unclear whether this process is truly scalable to a kg-scale or what the alternate process approach would be to help scale-up synthesis of the most promising materials. Is there an exit strategy for this project when a promising material is found?

Reviewer 5:

This project establishes an advance synthesis process, using supercritical fluids, able to obtain/tune such a very singular stoichiometry/composition for cathode materials, which this reviewer described as one of the main barriers to develop batteries beyond the present Li-ion battery technology. However, it is not quite clear from the information provided, why specifically a NMC96-2-2 cathode (focus of this study) would be better than, for instance, a NMC8-1-1. Are there strong differences between the $Li_{100}Ni_{96}Mn_2Co_2$ investigated in this project and the $LiNiO_2$? Are all the problems of the latter solved by including 2% of atoms of Co and Mn in the transition metal components? This reviewer pointed out that no explanation is provided. On the other hand, the supercritical technique allows, to some extent, the tuning of particle size and morphology, which are other barriers to developing new materials.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

This reviewer reported the following technical accomplishments: synthesis of single crystal NMC with high Ni has been well established using the HYST method; the particle morphology for single crystal NMC via this route has been shown to be improved; electrochemical performance for the materials synthesized via this method is superior; and effect of dopants were addressed as well.

Reviewer 2:

The reviewer stated that this project seems to be on the right track toward overall completion. The scheduled milestones so far have been concluded successfully and those in progress are providing the expected results.

Reviewer 3:

This reviewer indicated that the PI produced nice 9622 materials. The mechanical advantages of large single crystals are not necessarily sound with respect to theory especially under electrochemomechanically induced strains and stresses, but they may have other merit. The reviewer definitely liked the way the PI benchmarked the single crystal material to a polycrystalline materials. In terms of cycle life, a small advantage is seen depending on the comparison viewed (Slide 9 versus 19). The PI should also show results for rate.

Reviewer 4:

Single crystal NMC96-2-2 results are interesting and promising from the perspective of this reviewer, who also expressed interest in seeing more electrochemical cycling data and validation of these materials. For example, on Slide 19, it is not clear why some samples were stopped before 15 cycles and others went to 20+ cycles. For the normalized capacity presented, is that self normalized to the cell you tested or the practical expected capacity of the material? The reviewer further noticed the electrode composition is quite high in binder and carbon content (70:15:15) and inquired about the reason for that. Is this the composition that the project team would need longer term for materials? If yes, how does the project team expect to overcome the Wh/kg and Wh/L impacts at scale? How do these materials perform at higher charge and discharge rates?

Reviewer 5:

The reviewer commented that the research team has shown good progress in synthesizing particles of different size. Preliminary coin cell test shows a modest improvement in gravimetric capacity retention for 80 cycles. Al- or zirconium (Zr)-doped single crystal material show better cycle life, but the number of cycles (13) was too small for a definitive assessment. The long-term cycle stability of this new cathode material needs to be established. Also, the team needs to perform cycling experiments at different (higher) C-rates. The reviewer explained that mechanical properties of single crystal versus polycrystalline particles was also evaluated. The authors write about facet control of their single crystals, but no data was presented where particle growth rates along the [100] and [111] facet directions was enhanced/altered.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The syntheses of new materials was the modus operandi of this project observed by this reviewer. These materials are sent to several labs for further analyses with extremely sophisticated instrumentation. The group is doing these collaborations very successfully with key national laboratories and excellent universities.

Reviewer 2:

The reviewer stated that this project requires a wide range of collaboration mainly because of the different techniques employed to study the structural and electrochemical properties. The range of expertise across the collaborators are well identified and the material characterizations are performed accordingly enabling a better insight of the synthesized materials.

Reviewer 3:

This reviewer noted that the PI shows a nice synergistic collaboration among national laboratory and academia for a variety of physical characterization.

Reviewer 4:

There appeared to be good collaboration and integration of project tasks across the project team from this reviewer's perspective. Results were presented from team membranes at Brookhaven, University of Wisconsin, and UC Irvine. However, the role of Hunt Energy on the project is unclear.

Reviewer 5:

Collaborations seem strong to this reviewer, who expressed interest in seeing more industrial collaboration or a path toward further material validation that goes beyond half-cell coin cells with outside partners.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The main concern of scaling up the material for large cell manufacturing has been addressed, however, this reviewer saw that there are no clear paths on achieving this goal. The team has to address this during their next year and clearly define how they are going to achieve this enabling a large format cell testing and validation.

Reviewer 2:

Future work is well planned, although this reviewer suggested making further analyses comparing to other stoichiometries of the NMC cathodes instead of comparing several variants of the NMC96-2-2. Certainly, it is a good idea to evaluate the doping of Al and Zr, but it should be done also comparing with similarly doped presently used NMC cathode materials.

Reviewer 3:

The reviewer stated that the PI could have expanded on process development, what unique attributes of hydrothermal can further differentiate it from state-of-the-art manufacturing techniques. Also, there should be a plan for fabricating a material that can benchmark this technique versus state of the art in a one to one comparison to show the advantages.

Reviewer 4:

The reviewer noted that future plans seem like a natural continuation of what was presented. For electrochemical testing, are there any plans to test the NMC96 2 2 cathode materials at higher charge and discharge rates? For the future nanoindentation work, it is not clear how much these results will translate to eventual macro-scale electrode performance (both mechanical and electrochemical). While these tests are important for basic material property quantification, it was unclear to this reviewer if any macro scale tests or composite electrode tests will eventually need to be performed. For the samples provided to external collaborators for evaluation, will there be a feedback loop wherein industrial or academic collaborators provide input on the utility of the synthesized materials?

Reviewer 5:

The reviewer recommended that future work should focus more on the performance of cathode material in pouch cells. Long term cycling needs to be performed at different C-rates; 20-80 cycles is insufficient to determine if single crystal particles are superior to polycrystalline powders. When synthesizing new single crystal powders, the PI should establish and justify a targeted set of properties. Why do the current doped particles require further improvement? What is the targeted capacity loss after 300, 500, and 1,000 charge/discharge cycles? An economic analysis of the hydrothermal process is also needed. What is the extra cost for single crystal particle synthesis versus the benefits of employing such particles in a Li battery cathode? Would it be possible to perform bench-scale continuous flow reactor experiments?

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer stated that this project supports DOE objectives in examining an alternative processing technique for electrode materials and identifying whether advantages exist.

Reviewer 2:

The reviewer observed an interesting approach that supports DOE's current objectives as a path toward higher energy density batteries.

Reviewer 3:

The reviewer reported that overall aims of this research project are to improve the performance and loading of Li battery cathodes. The work may have spin-off implications/applications for other battery materials.

Reviewer 4:

This reviewer described this project as well aligned with DOE's goal of developing high quality Ni-rich, low Co containing NMCs. However, the presentation has no clear mention on the economics of this method compared to the traditional Single crystal synthesis methods.

Reviewer 5:

This project supports DOE objectives; however, in the opinion of this reviewer, the project should also consider the theoretical limitations of strongly increasing the amount of Ni in NMC materials. Without such an analysis, the reviewer is not fully convinced that the materials being developed are going to be of importance for DOE. The mayor question is: what is the difference between a 98-1-1 from a 99-1-0, 99-0-1, 100-0-0, and the like?

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

This reviewer described a well-aligned team to understand multiple aspects of the material properties.

Reviewer 2:

This reviewer observed an appropriate funding level for the work presented.

Reviewer 3:

The reviewer noted adequate resources for the project.

Reviewer 4:

Resources seemed sufficient to this reviewer.

Reviewer 5:

Without LOE or burn rate, this reviewer could not comment on this. However, funding seems adequate especially as much of the characterization is done collaboratively by others.

Presentation Number: bat472
Presentation Title: Behind-the-Meter-Storage (BTMS)–Materials
Principal Investigator: Kyusung Park (National Renewable Energy Laboratory)

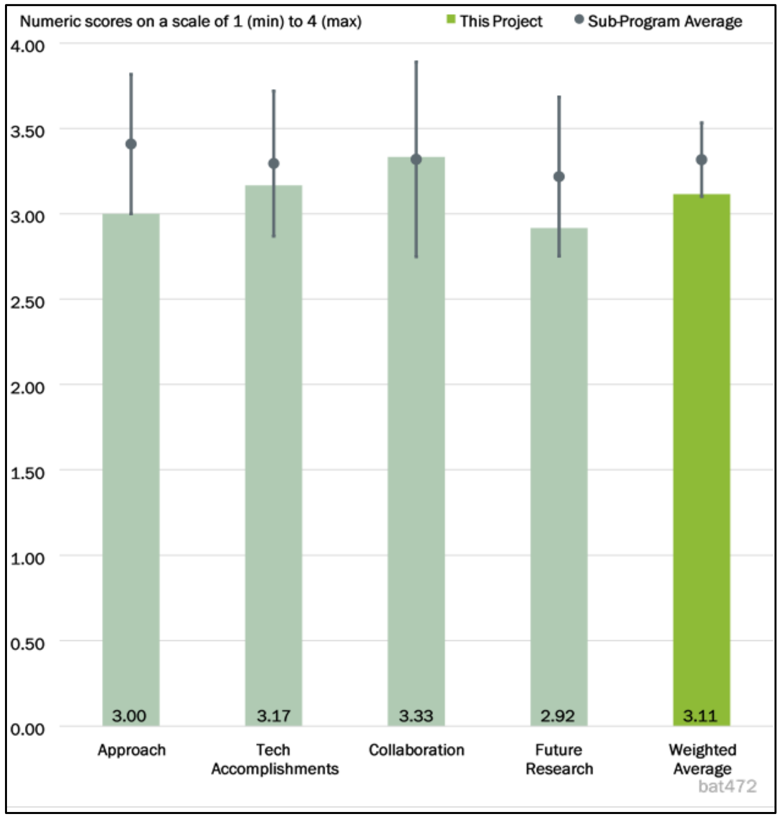


Figure 2-31 - Presentation Number: bat472 Presentation Title: Behind-the-Meter-Storage (BTMS)–Materials Principal Investigator: Kyusung Park (National Renewable Energy Laboratory)

Presenter

Kyusung Park, National Renewable Energy Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 17% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer remarked that the work is meaningful and addresses DOE VTO goals of developing a total battery focused energy system. Storage is paramount to success and the work accomplished stated goals.

Reviewer 2:

The reviewer indicated that using locally-sourced battery materials is an important step in broader adoption of battery technologies.

Reviewer 3:

The reviewer reported that key barriers were identified as battery cost, cycle life, sustainable materials, and energy density for behind-the-meter-storage (BTMS) batteries. These generally make sense, but it would be useful to have specific quantitative technical targets for BTMS and show gap analysis for commercially existing batteries. Certainly, cycle life and cost (and sustainable materials as a subset of cost) are key issues for BTMS. However, energy density is less clearly a critical barrier. For stationary applications, this reviewer explained that the energy density targets are not as challenging as for EVs. This may be implicitly understood since LTO batteries are lower in energy density than EV battery targets. Higher energy density is still useful however in reducing cost, which is a very critical barrier. The reviewer agreed that safety is perhaps a more critical barrier for large BTMS batteries inside buildings.

This reviewer noted that good approaches were developed to address these barriers including designing electrolyte for safety, using high-rate, high cycle life LTO battery technology and focusing on cycle life development. The focus on thick electrodes was said to be aimed at improving energy density, which would not seem to be a critical barrier. However, this would have more of a favorable effect on lowering cost which is a critical barrier. Again, it would help to have quantitative technical targets.

The starting battery cathode chemistry is excellent in its lack of critical materials (no Co and no Ni). Thus, why there were efforts into studying LiNiMn oxides and LiNiMnCo oxides was a little puzzling to this reviewer. The reviewer further commented that this project does address the technical barriers and the project is well-designed and feasible.

Reviewer 4:

The reviewer stated that the critical-material-free chemistries should be investigated for many applications; so, this reviewer was glad to see this project. Is it necessary to be concerned about the flash point of the electrolyte with relatively low energy safe active materials? The reviewer asked whether there is any SEI or lithium plating to worry about, or any oxygen release from the cathode. Also, a requirement to prelithiate a system where you already have lithium in both your cathode and anode seems inefficient. This reviewer was unconvinced that LTO is the way to go here. Why not graphite? Perhaps, this is just for learning, not a commercial product. The reviewer further indicated that Mn dissolution from LMO is well known and there are many solutions/mitigations that should be implemented.

Reviewer 5:

The reviewer stated that the LMO/LTO is not a great approach or starting point. Both LMO and LTO have been well developed in industry. For example, LMO has been widely used as cathode in two-wheeler batteries because it is cheap and has a life of about 500-700 cycles. Due to the Mn dissolution, its cycle life is very limited. LMO’s capacity is also low comparing to other cathode materials. The reviewer explained that LTO has also been well developed in industry and has magnificent stability. However, its high cost and high operating voltage compared to graphite anode is very limited in its applications.

In this project, there are also a lot of ongoing efforts on thick electrode investigation that are not very useful in a national laboratory or university because more depends on processing and equipment. The reviewer asserted that it is a must for every battery company to develop a process that makes good thick electrodes based on its equipment capability.

LTO anode makes it possible to use sole PC or EC as electrolyte solvent. However, this reviewer recommended that efforts should be made to develop the electrolyte for normal temperature operation, not at 40°C.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer observed excellent progress/accomplishments made based on the existing plan, and noted that very detailed results were presented.

Reviewer 2:

This reviewer noted the work met stated standards as described in original project and the investigative work has led to a functional approach to energy storage. Further efforts may yield viable technology to support next generation energy infrastructure.

Reviewer 3:

The reviewer reported that the team has demonstrated feasibility of LT/LMO cells.

Reviewer 4:

The reviewer stated that this project shows substantial progress with excellent technical accomplishments aimed at overcoming barriers. An improvement would be to include specific quantitative technical targets.

The reviewer described cycle life result of 98% capacity retention after 1000 cycles of 1C rate charge-discharge for the prelith EC as impressive and consistent with the excellent 99.99% coulombic efficiency. The detailed study of degradation modes is also excellent and shows approaches to further improve cycle life. Further insight from XPS and TOF-SIM depth profiles is also impressive. The reviewer asserted that this is first class R&D work.

The reviewer did not quite understand the motivation for the additional work on Ni and Co containing cathode materials if LMO works so well.

This reviewer commented that pouch cell evaluation results on Slide 13 do not look as promising as the cycle life results on Slide 7. The results on Slide 13 show a strong dependence of performance and cycle life on electrode thickness. Slide11 also shows a dependence of performance on vendor. There is probably a big dependence on processing techniques and this reviewer suggested that things like dry electrode processing may be beneficial for thicker electrodes.

Reviewer 5:

It seemed to this reviewer that there are many problems—the LMO has Mn dissolution and the LTO thick electrodes do not work well. The evaluation of LNMO (higher voltage)/LMO can improve energy density, but requires a high voltage electrolyte. It is not clear where this project is going until 2025.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer remarked that this project does a very good job of working in teamwork with partners and those collaborations have been detailed.

Reviewer 2:

This reviewer indicated that the team at NREL is effectively using CAMP and INL for their specific expertise.

Reviewer 3:

This reviewer observed a competent team is competent and effective collaboration.

Reviewer 4:

The reviewer noted that team coordination was necessary to accomplished presented work. It seems that all involved performed as expected and required to yield successes reported by the researcher.

Reviewer 5:

This reviewer recommended seeking industrial collaboration on the thick electrode development and large pouch cell manufacturing.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

Future plans are sound from this reviewer's perspective.

Reviewer 2:

The reviewer described proposed future research as great based on the existing plan. However, as previously indicated, LMO/LTO is not a great approach; LMNO could be a great alternative.

Reviewer 3:

This reviewer asserted that work needs to continue, and further commented that storage capability of generated energy is of paramount importance to complete a total renewable energy system. Proposed future efforts need to be supported and addressed.

Reviewer 4:

This reviewer indicated that the proposed future research plan is excellent and further focuses on cycle life. Again, the reviewer did not understand the continued focus on layered oxides if the LMO spinel materials with no Ni and no Co work. Furthermore, this reviewer highly recommended development of targeted quantitative technical targets for energy density, cost, and cycle life. It would also be good to develop technical targets for safety for the BTMS applications.

The reviewer also recommended a cost analysis including not only the materials cost, but also some estimate of the manufacturing cost and cost comparison of existing LIB battery products including LTO batteries. LTO batteries are theoretically inexpensive. However, in practice there are complex and troublesome issues with formation and other manufacturing processes that are reflected in current pricing of these batteries.

Reviewer 5:

This reviewer did not see approaches proposed to solve the problems that have been encountered. These are "old" chemistries and the problems are well known. The reviewer asked what the team is doing differently to solve them.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer stated that yes, this project is relevant to DOE objectives in the area of BTMS, which should help the proliferation of fast-charge stations. The overall BTMS initiative is excellent and this project provides excellent support and development of batteries aimed at this application. Within the BTMS initiative it would also be useful to examine the suitability of existing battery products in detail.

Reviewer 2:

The reviewer commented that evaluation of chemistries that do not require critical materials is essential for U.S. energy dependence during the transition from hydrocarbons to electricity, which requires batteries.

Reviewer 3:

The reviewer stated that non- or low-Co chemistries would support the overall DOE objectives due to very limited Co resources and very high demand of LIB in EV and ESS markets. The development of non- or low-Co chemistries would be critical for the independence of the U.S. LIB industry.

Reviewer 4:

This reviewer asserted that the work presented definitely supports DOE VTO efforts to enable a total renewable energy system.

Reviewer 5:

Developing BMT technology that does not use critical materials is relevant to DOE objectives from this reviewer's perspective.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

The reviewer indicated that this project does a very good job of utilizing existing resources through collaboration.

Reviewer 2:

The reviewer commented that industrial collaboration is critical for the thick electrode development and evaluation, as well as large format pouch cell manufacturing.

Reviewer 3:

Funding appeared adequate to support current and proposed work from this reviewer's perspective.

Reviewer 4:

Resources were described by this reviewer as sufficient.

Reviewer 5:

This is hard to answer as the reviewer could not tell what the future proposed efforts entail. Therefore, the reviewer concluded that there are sufficient resources.

Presentation Number: bat473
Presentation Title: Behind-the-Meter-Storage (BTMS)–Analysis
Principal Investigator: Margaret Mann (National Renewable Energy Laboratory)

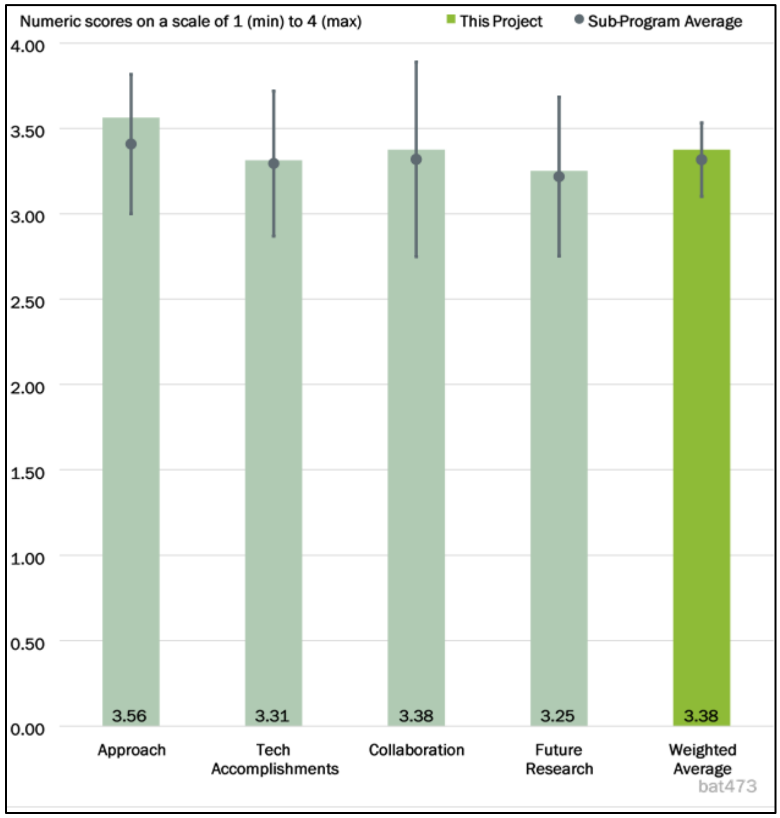


Figure 2-32 - Presentation Number: bat473 Presentation Title: Behind-the-Meter-Storage (BTMS)–Analysis Principal Investigator: Margaret Mann (National Renewable Energy Laboratory)

Presenter

Margaret Mann, National Renewable Energy Laboratory

Reviewer Sample Size

A total of eight reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 25% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer commented that this looks like an excellent project with excellent potential.

Reviewer 2:

This reviewer indicated that BTMS analysis is a critical need for understanding how both vehicle charging (especially DC fast charge) and increased use of rooftop solar impact the grid and how BTMS can be optimized to manage that impact. The selected analytical methods and models appear sound and the reviewer looked forward to seeing how this project progresses.

Reviewer 3:

The reviewer indicated that BTMS optimization is good idea as it is based on a detailed, physics-based model. Predictive control of BTMS could solve cost and grid impact issues. Sensitivity analysis for variability faced by BTMS is part of the approach and this reviewer asserted that it is a good idea to consider effects variability in the BTMS operation.

Reviewer 4:

The reviewer stated that this project focuses on examining how behind-the-meter systems can minimize unexpected charging costs and enable fast EV charging applications. This thrust proposes to use physics-based modeling and predictive controls to evaluate the potential for BTMS to address charging costs and grid impacts of fast EV charging. The project team is developing a detailed, physics-level understanding of the interaction of the various components and systems to optimize BTMS design and operation. In particular, the project team is looking at the analysis sensitivity, impact of new research achievements, iterative feedback modeling, and potential energy savings as inputs to its model among other variables.

Reviewer 5:

The technical barriers of the energy storage and generation behind the meter are well addressed from this reviewer's perspective. It is suggested that technical goals such as the specific power density, power density, etc., can be further detailed so the researchers can work toward them.

Reviewer 6:

This reviewer remarked on the importance of determining the cost-benefit ratio in doing DCFC. The approach to model the best strategy to meet DCFC demands at a grid level is well designed.

Reviewer 7:

The reviewer observed a very complex but necessary task to analyze the Behind-The-Meter-Storage (BTMS) system. Extensive analysis is needed to understand the trade-offs between the dynamic loads, on-site generation and BTMS energy storage affected by various parameters listed in Slide 8—climate region, battery lifetime, efficiency of EVs. The proposed EnStore model on Slide 9 that integrates existing underlying models, e.g., battery lifetime model, is a good approach to analyze the complex task. Levelized cost of charging (LCOC) was proposed as the metric to measure efficiency of the BTMS system. However, metrics are also needed to quantify the reliability and resilience of the BTMS system.

Reviewer 8:

This reviewer acknowledged lacking enough knowledge in the topic to give it an outstanding rating. Nevertheless, all ratings in this review are awarded on technical merits. The reviewer indicated that the technical merits of what is needed in this project were fully addressed and described the data as invaluable and insightful. It shows where and what problems need to be addressed in densely populated city areas. While good to see that addressed, rural areas should be addressed as well. Rural areas are the last problem to solve as it serves the least number of people, but farm equipment serves all people; so, it too will need to be addressed, but the reviewer expected a stripped or mobile BTMS system will be implemented in rural America.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer reported that the EnStore model provided examples of peak power profile and dynamic loads for specific scenarios and illustrated the complexity of the BTMS system. Optimized LCOC was also modeled for different climate regions at various utility rates, successfully illustrating the feasibility of the EnStore model.

Reviewer 2:

This reviewer reported that Slide 15 indicates that the project has made great progress.

Reviewer 3:

The reviewer stated that this looks good and appears to be ahead of schedule.

Reviewer 4:

It seemed to this reviewer that the plan is ahead of schedule.

Reviewer 5:

Impressive technical achievements were noted by this reviewer. As a comment to the overall BTMS project, it is unclear how this project leverages previous activities such as battery research efforts funded by DOE for numerous years.

Reviewer 6:

The reviewer indicated that there are some amazing accomplishments that were made in collecting data and information to feed the model. However, there is still notably more that needs to be done to make it more relevant and applicable to real world conditions.

Reviewer 7:

This reviewer stated that the project has developed an EV Charge Profile and predictive control model to better model energy flows within the BTMS system. It was challenging to understand the scale of the overall technical accomplishments, although the presenter did show that BTMS can reduce costs of fast EV-charging for two specific scenarios (PG&E and ConEd) by 30-40%, which is impressive. The reviewer explained that it will be critical to see how well this process can be generalized to other scenarios and to understand what the return on investment (ROI)/payback period would be for the large battery storage infrastructure costs.

Reviewer 8:

The reviewer remarked that the project is still near the very beginning, but the analytical methodology appears to be sound.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The collaborations across the team members appeared excellent to this reviewer.

Reviewer 2:

The reviewer observed outstanding collaboration and coordination across all project teams.

Reviewer 3:

This reviewer reported that this project is part of a wider collaboration between five national laboratories and appears to have sufficient collaboration and coordination between project institutions.

Reviewer 4:

This reviewer noted that complexity of the BTMS system necessitated collaboration with other DOE offices such as the Office of Electricity (OE), Building Technologies Office (BTO), and Solar Energy Technologies Office (SETO).

Reviewer 5:

Although this was not discussed in detail, the reviewer indicated that this seems good based on other presentations.

Reviewer 6:

The reviewer stated that many DOE offices and labs are working together.

Reviewer 7:

Rather than relying solely on sensitivity analysis for the battery costs for BTMS, the reviewer thought that collaboration with ANL could be improved. The ANL BatPaC model appears to be capable of modeling bill of materials and costs for all of the cathode/anode chemistries under consideration for BTMS. Subsequently, the reviewer recommended incorporating BatPaC modeling into the project team's cost analyses and identified the primary POC for BatPaC at ANL, Shabbir Ahmed.

Reviewer 8:

This reviewer stated that the data is clearly coming from the utility industry in different areas. This is supposed to be a joint project between VTO, BTO, OE and SETO and a five-laboratory team including SNL, ANL INL, and PNNL, and the reviewer emphasized that it probably is. Slide 27 finally is explicit about who is doing what. The reviewer could not identify where the collaboration and coordination come from in Slides 3-26 given the unfamiliarity with the project. Slide 10 does credit data sharing, but this reviewer was unsure if this is related to the collaboration in the overview slide.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

This reviewer indicated that proposed future research topics include (1) running scenarios for three of five building types, four of six climate regions, battery costs, PV costs, battery lifetime, and battery chemistry impacts; (2) public-facing visual interface for exploring the potential of BTMS under changing scenarios; and (3) GHG emissions savings compared to no BTMS at locations across the United States and at different levels of EV deployment. These activities will be quite helpful to understand BTMS far better than the present state of know-how on this topic.

Reviewer 2:

The proposed analytical blueprint for future work is sound from this reviewer's perspective.

Reviewer 3:

Although this was not discussed in detail, the reviewer indicated that this project has an achievable plan for future work.

Reviewer 4:

This reviewer stated that the proposed future research was largely focused on more data analysis and fancier ways of displaying data—in the other proposed research and beyond the scope of the contract. The reviewer expressed interest in seeing a more science-based project; there is no here are proposed theories or ways of testing those theories, or the project team does not have a model for X and we need to create it. The proposed research is limited to Engineering-Fiscal studies of tabulating with and without BTMS and EV usage, and calculating more accurate constants in the energy flow models, of which all are useful.

Reviewer 5:

This reviewer indicated that there are too many variables that need to be applied to the model to make it more applicable. That requires lot more effect and time that is available to complete the project. The focus needs to be updated or more time and resources needs to be provided.

Reviewer 6:

The reviewer observed well-illustrated barriers for future work. It is suggested that supercapacitors be considered in BTMS analysis considering its super power capability and long cycle life, though its low energy density may be a drawback.

Reviewer 7:

The reviewer reported that the project proposes to run scenarios for the remaining building, climate regions and for various battery and photovoltaic (PV) inputs. Most interesting would be potential future partnerships with charging and vehicle industries to rollout this model and learning to provide cost advantages to companies and individuals.

Reviewer 8:

This reviewer explained that the stationary battery is needed to buffer against instability to the grid from XFC charging. The project team should use its model to provide guidance on BTMS stationary battery's energy density and power density targets. The BTMS team should publish the energy density and power density targets for the stationary battery. The reviewer asked whether the BTMS battery needs to have very high energy density (per BAT472 talk by Park) and indicated that a higher energy density battery usually has lower cycle life and shorter calendar life. A high-power stationary battery with medium energy density may be sufficient as a BTMS battery. Given the complexity of the energy flow in the BTMS system, future research should focus on validating the energy flow modeling results.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer asserted that this study is clearly needed. This reviewer could see the advantages of a BTMS on delivering enough fast charge to the consumer and minimizing costs to the utility supplier. Given that demand will go way up, it looks like the model will not be undercut by savings being used to justify rate hikes. It also looks like this work will provide the necessary work for building owners to justify investments in BTMS systems. Recognizing the resulting model is not a one-size-fits-all makes it even more invaluable. This work is clearly a pillar in its area.

Reviewer 2:

This reviewer highlighted that it is very important to optimize the grid-level approach to DCFC to make it more applicable to consumers.

Reviewer 3:

The reviewer remarked that this project does support the overall DOE objective because it targets a reduced cost of ownership for EVs, thereby increasing adoption and lowering GHG emissions and potentially improving U.S. energy independence.

Reviewer 4:

This reviewer indicated that these analyses will be critical in developing full assessments of EV DCFC costs and challenges.

Reviewer 5:

The reviewer opined that good understanding of the BTMS is critical for success of the EV ecosystem.

Reviewer 6:

Understanding BTMS effect on electric grid itself is quite relevant to Americans from this reviewer's perspective. Then BTMS' usefulness in reliable EV charging without impacting grid due to availability of local charging by renewable sources could make BTMS quite relevant and attractive.

Reviewer 7:

This reviewer stated that reducing the cost of charging would benefit electrification.

Reviewer 8:

This reviewer explained that a detailed physics-level understanding of the interaction of various components and systems—including energy storage, PV, etc.–is needed to economically optimize the design and operation of BTMS.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer asserted that more resources are needed for the BTMS analysis given the complexity of the BTMS system.

Reviewer 2:

The reviewer commented that more time and resources need to be provided to complete the objectives set at the start of the program.

Reviewer 3:

The reviewer asserted that the team is well resourced. Many DOE offices and DOE labs are working together and contributing to this project's success.

Reviewer 4:

This project is ahead of its time (as opposed to last minute), which the reviewer described as good because it provides timely data before future action is past due.

Reviewer 5:

The reviewer observed appropriate resources assigned to this project.

Reviewer 6:

The reviewer described project resources as sufficient to achieve the stated milestones.

Reviewer 7:

Although this was not discussed in detail, funding seemed sufficient to this reviewer.

Reviewer 8:

The project appears to be on schedule, and this reviewer remarked that there was no indication that resources were a significant issue.

Presentation Number: bat475
Presentation Title: Towards Solventless Processing of Thick Electron-Beam (EB) Cured Lithium-Ion Battery Cathodes
Principal Investigator: David Wood (Oak Ridge National Laboratory)

Presenter

David Wood, Oak Ridge National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 67% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 33% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

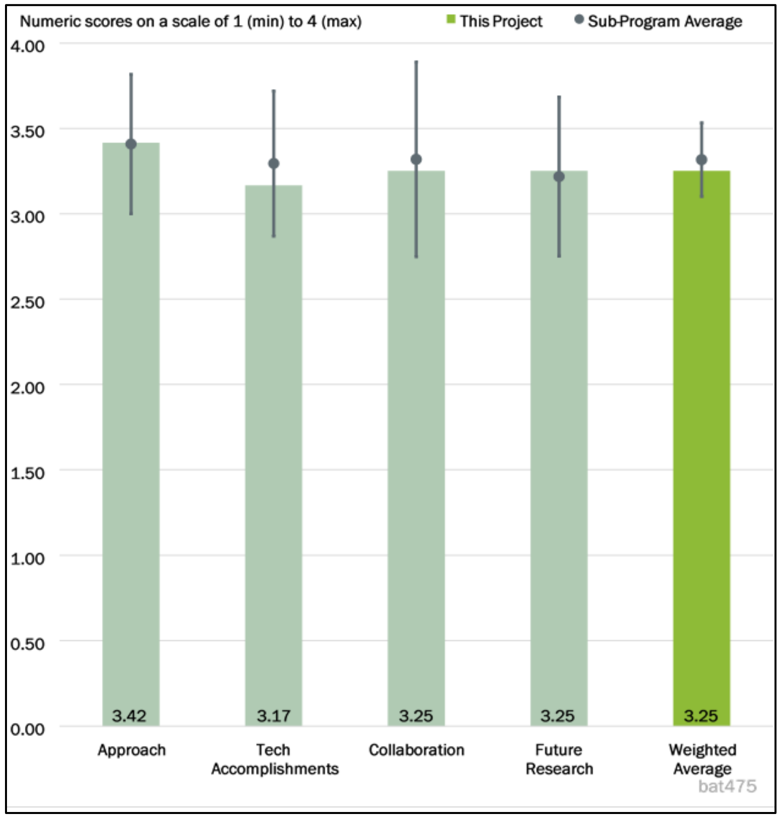


Figure 2-33 - Presentation Number: bat475 Presentation Title: Towards Solventless Processing of Thick Electron-Beam (EB) Cured Lithium-Ion Battery Cathodes Principal Investigator: David Wood (Oak Ridge National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer explained that EB curing is one of the novel methods that can efficiently implement solvent free dry electrode fabrication method and the project has critically approached this task. Electrode loadings of approximately 30 mg/cm^2 is the need of the hour to achieve high energy density. The reviewer asserted that practicing this approach with NCM811 is extremely important. Novel approach of EB curing has been validated at pilot scale, which demonstrates the serious efforts undertaken by the team.

Reviewer 2:

The reviewer observed a novel approach novel that can be tailored for designing different cell components, including cathodes and solid electrolytes. The team has also evaluated the electrode performance with its internally developed V2 electrolyte.

Reviewer 3:

The reviewer commented that the research team has developed an interesting and effective approach to cathode fabrication that does not involve an electrode drying step. Preliminary electron beam (EB)-cured cathodes worked well in terms of capacity retention during charge/discharge cycling, but the cathode contained binder oligomers with some solvent during curing. The reviewer explained that electron-beam curing is fast and the method can be incorporated into roll-to-roll processing schemes. The research team has shown that EB curing may be economically attractive in terms of manufacturing cost.

Reviewer 4:

The reviewer asserted that EB curing was a innovative approach for low cost and high energy Li-ion electrode production. The approach could enable thick electrode production, unlike ultraviolet (UV) ray, the high energy of EB can cure a thick electrode. It seemed to this reviewer that a slot die was still used to cast electrode slurry. Is this a solventless process?

Reviewer 5:

This reviewer indicated that the project is generally effective and contributes to overcoming the barriers in the development of cathodes with little or no solvent using EB curing, which can significantly reduce the drying/fabrication time for electrodes compared to conventional solvent-based electrodes. The reviewer explained that this will enable the fabrication of dense (with high active material loading corresponding to 4 mAh/cm^2) cathodes with faster processing speeds, reduced footprint and infrastructure for the (drying) equipment, and thus, a reduction in overall cost. Subsequently, the project addresses the two significant barriers of current EV batteries, i.e., specific energy and cost. With little or no solvent in the fabrication process, the EB curing method minimized or even eliminates environmentally incompatible solvents (e.g., NMP) and the problems associated with its use. The reviewer stated that the method looks promising for the current Li-ion battery technology using metal oxide/phosphate cathodes and may also be extended to the fabrication of composite cathodes for solid-state batteries with conducting polymer as a binder.

As a weakness, and with promising results from the last two years, it was surprising to this reviewer that there has not been as much interest from the major Li-ion cell manufacturers. What is the reason for this lack of interest from the commercial battery manufacturers? Secondly, why is this not being extended to the fabrication of graphite anode instead of composite solid electrolyte films?

Reviewer 6:

The concept of EB based coatings is one worth exploring from this reviewer's perspective. The machines can be notably more compact than coating machines based on solvent evaporation, thus having a smaller foot print in the manufacturing setting. This could lead to lower cost more environmentally-friendly methods.

Several items that still need to be addressed were identified by this reviewer. The method in current development still uses approximately 10% solvent. Further minimizing or removing the solvent would be important in order to facilitate scale-up. Additionally, the reviewer indicated that details on the speed that would be possible for full-scale manufacturing need to be provided. Is there a limit on electrode thickness based on the ability of the EB to penetrate the coating? The reviewer also reported that nitrogen is currently used as a cover gas, and that careful quantification of nitrogen consumption is important for a final cost analysis

A technical comment is that while the group explored the bulk characteristics of the active material after exposure to the EB, the reviewer suggested that the project team should also look into the surface condition of the material. This could be done by soft XAS depth profiling or possibly some information could also be gained from XPS analysis.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer commented that project investigators have studied the electrode fabrication process using EB curing method at very high loading with the next generation cathode material. Additionally, high speed coating of the electrodes using the method has been well validated at a pilot scale level. The project has also looked into any side reactions because of the exposure of the electrode to the EB and have established a systematic study in understanding the cation mixing at various energy levels of the EB.

Reviewer 2:

The reviewer stated that the progress is adequate and the prospect is clear. The team has established the fabrication capability at this point, which will help accelerate the next phase of research.

Reviewer 3:

The reviewer noted good progress has been made toward the projective objectives. Specifically, the Roll-to-roll (R2R) EB curing pilot line for cathode fabrication has been successfully installed at ORNL to add to the capabilities of the laboratory. Thick cathodes of NMC 811 were demonstrated, which showed impressive capacity retention during cycling. EB Radiation does not seem to impact the crystalline properties of the active material, though there is increased cation mixing at high radiation levels. This reviewer expressed surprise that performance of the EB-cured cathode was demonstrated in different electrolytes, but a direct comparison with the conventional solvent-based cathode has not been provided. Finally, this technique has been demonstrated Li ion conducting polymer as a binder for composite cathode with stable cycling. Cost analysis were made which show substantial operating and capital cost reduction with EB Processing. There is a good possibility for the technology transfer because of the significant electrode production cost reduction, and impact on cell energy density.

Although not weakness per se, the reviewer suggested that it is probably an appropriate time to investigate the applicability of this method to "Beyond Li-ion Technologies," specifically, Si anode sulfur cathode.

Reviewer 4:

A pilot level demonstration coater with EB curing was set up on schedule as observed by this reviewer. The coated electrodes were tested, and adequate results were demonstrated. It seemed to the reviewer that the electrodes shown in the photo on Slide 7 were not roll-to-roll production.

Reviewer 5:

Good progress has been made in demonstrating the process. As noted previously, the boundary conditions in terms of electrode thickness, web speed, material damage, and nitrogen consumption still need better definition in order to transition to large scale manufacturing.

Reviewer 6:

Although research progress is very good, this reviewer highlighted that the research team has yet to show that EB curing will work when there is no solvent in the oligomeric binder. Was the solvent providing sufficient oligomer mobility (plasticization) for proper crosslinking? The reviewer explained that without solvent, the efficiency and extent of crosslinking will be reduced. The PI did not indicate whether the use of a binder with 10% solvent will require a drying oven with the EB reactor in a roll-to-roll process scheme. Also, there is still the need for calendaring and it is not clear if this step was included in the economic analysis of EB manufacturing cost. This reviewer also noted that there was no discussion of the reproducibility of EB cured cathodes.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer indicated that the team is highly collaborative and has involved multiple companies in their network. The team has also established collaboration with their neutron source.

Reviewer 2:

Collaborations appeared effective to this reviewer, who also noted that the project has involved material manufacturers and equipment suppliers among others. The project team has an appropriate diversity of engaged partners.

Reviewer 3:

It appeared to the reviewer that the PI collaborated with both equipment suppliers, raw material manufacturers, and battery manufacturers well.

Reviewer 4:

The reviewer stated that the team is well crafted across different battery material, cell, and equipment manufacturers. Given that the project is 84% complete, the roles of individual collaborators are not clearly mentioned during the presentation. Charting out the individual contributions will be very helpful to understand the scope of the collaboration.

Reviewer 5:

Ongoing collaborations with equipment suppliers were reported by this reviewer, including PCT EB and Integration, Keyland Polymer, B&W MEGTEC, and Eastman Kodak; battery manufacturers including XALT Energy and Navitas Systems; and raw materials suppliers including BASF, Allnex, Keyland Polymer, Superior Graphite, and Denka

As a weakness, the reviewer commented that the collaboration is non-specific and the commercialization opportunities are not bright with these collaborators. A more useful partnership would be with a major cell manufacturer, if possible.

Reviewer 6:

There was little discussion of collaborative work in the AMR presentation observed by this reviewer, and it was not clear how equipment suppliers and battery manufacturers are contributing to the project.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer indicated that proposed future studies will focus on extending the EB curing to graphite anodes (this is quite appropriate) and to EB/UV R2R polymer electrolyte and composite cathode for solid state lithium cell and demonstrate high energy density and good cycle life. This project has effectively planned its future work in a logical manner by incorporating appropriate technology metrics, considering barriers to the realization of the proposed technology and, adopting suitable approaches to progress toward project objectives.

Reviewer 2:

This reviewer noted future research has been clearly stated, with some battery performance metrics stated as well.

Reviewer 3:

The reviewer stated that the research team needs to demonstrate that EB curing can be carried out with no solvent in the binder. The project team needs to show reproducible cathode performance. The PI showed that an EB cured cathode works well at high C-rates, but this might be due to the use of a newly developed electrolyte. The reviewer explained that the team needs to identify if EB curing produces a better electrode morphology, or it just eliminates the need for large drying ovens (with long residence times) in a roll-to-roll process. The economic analysis should include capital equipment and equipment replacement costs, not just manufacturing costs. What is the lifetime of the EB reactor? Will this be an issue that might affect the economic analysis?

Reviewer 4:

The reviewer remarked that future research is in three categories—EB curing of anodes, EB/UV for polymer electrolyte, and understanding of processing-microstructure-performance relationships. For a process development project like this one, Design-of-Experiment is a good tool to understand the interaction of many parameters. This reviewer suggested that instead of expanding the EB to many systems, more attentions should be focused on item 3 on Slide 14.

Reviewer 5:

The reviewer commented that future work proposed focused on breadth rather than depth. For example, the project team wants to demonstrate coating of anode materials and solid-state batteries. While these are of interest and worthy under takings, it would be of interest to fully define the cathode parameters such that most questions are answered. This may facilitate transition to a manufacturing company. Thus, the reviewer indicated that there may be a short-term trade-off of depth versus breadth of the technique. It may prove that short-term investment in detailed understanding will provide benefit for future processes as well.

Reviewer 6:

The reviewer explained that studying anode is another important aspect of battery research and establishing the cycle life of EB cured electrodes will be very helpful to understand the benefits of this technique. The plan to study long cycle performance of the high energy density cell with EB/UV cured solid electrolyte and electrodes is an important milestone to meet, mainly to see the benefit of this technique of fabricating battery grade electrodes and electrolytes. The proposed study to understand the electrode microstructure is significant; it will answer the effect of making electrodes with this technique on fast-charge capability of the cell incorporating the electrodes using this novel method.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer commented that proposed research could enable the manufacture of low-cost and high energy thick electrodes. Such advanced production processes will not only produce high energy density Li-ion batteries, but also make U.S. production more competitive.

Reviewer 2:

This project supports overall DOE objectives because it supports cell design targeting higher energy density; lowers $/kWh because of the cost reduction; and envisions a universal approach on fabricating anode, cathode, and electrolyte, which has merit in incorporating this method across the board of battery manufacturing process.

Reviewer 3:

The reviewer indicated that the project supports the overall DOE objectives by developing a novel, low-cost and environmentally friendly fabrication using EB/UV curing for dense and high areal capacity cathodes for improving specific energy and reducing the cost of LiBs. Overall, the reviewer asserted that this is relevant to DOE VTO’s battery programs and supports its objectives.

Reviewer 4:

The reviewer stated that the process is able to make thicker electrodes with lower cost and environmental friendliness. These are important factors for battery manufacturing and clearly relevant to DOE missions.

Reviewer 5:

The reviewer remarked that the overall aims of this research project are to decrease the processing time and simplify the processing steps to manufacture Li-battery electrodes. Both objectives are important and worthwhile.

Reviewer 6:

This project paves a lower cost environmentally friendly path, and if the questions previously posed can be resolved, then the reviewer opined that this meets DOE objectives nicely. A focus on deeper understanding and more quantitative results prior to moving to other systems would be useful. The reviewer acknowledged the possibility that the team may already have the results and did not wish to present the details to a broad audience.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer indicated that resources are commensurate with the scope of the project and adequate to achieve the stated milestones.

Reviewer 2:

This reviewer commented that resources appeared sufficient for the proposed projects.

Reviewer 3:

Adequate project resources were noted by this reviewer.

Reviewer 4:

This reviewer stated that the team has established fabrication capability to move the project forward.

Reviewer 5:

As mentioned previously, this reviewer observed the collaboration team enables a wide range of resources and the outcome because of this larger collaboration that has not been highlighted in the presentation.

Reviewer 6:

The reviewer remarked that the PI has access to more than adequate resources to complete the proposed milestones.

Presentation Number: bat478
Presentation Title: Development of Thin, Robust, Lithium-Impenetrable, High-Conductivity, Electrochemically Stable, Scalable, and Low-Cost Glassy Solid Electrolytes for Solid State Lithium Batteries
Principal Investigator: Steve Martin (Iowa State University of Science and Technology)

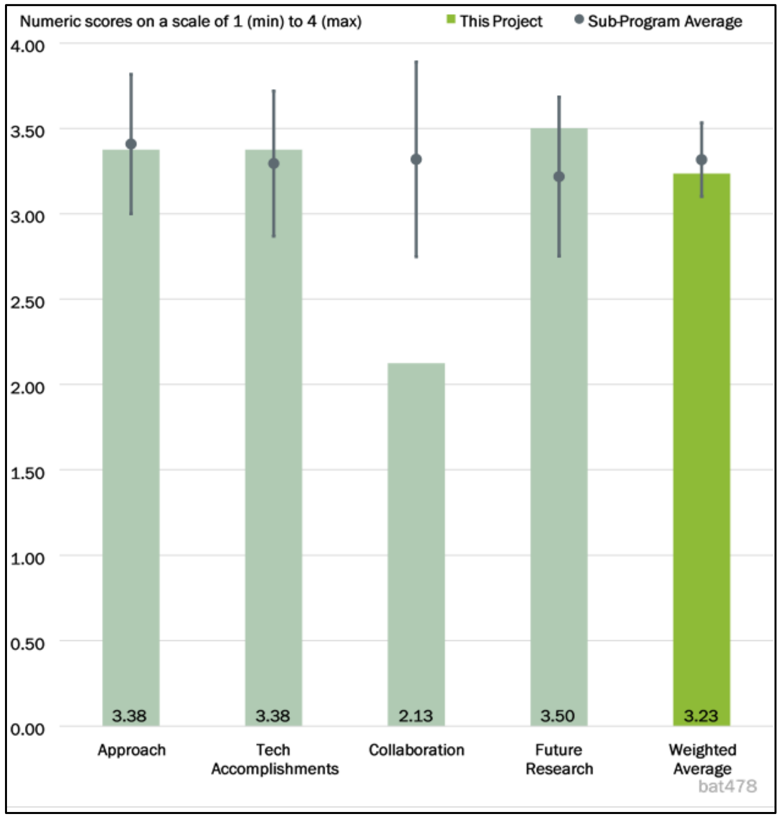


Figure 2-34 - Presentation Number: bat478 Presentation Title: Development of Thin, Robust, Lithium-Impenetrable, High-Conductivity, Electrochemically Stable, Scalable, and Low-Cost Glassy Solid Electrolytes for Solid State Lithium Batteries Principal Investigator: Steve Martin (Iowa State University of Science and Technology)

Presenter

Steve Martin, Iowa State University of Science and Technology

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 25% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

Development of the glassy solid electrolyte is an effective way to improve the Li-anode/electrolyte interface, which this reviewer described as critical for the performance of all-solid-state batteries. The team has demonstrated its ability to make thin and Li-impenetrable glassy solid electrolytes (GSEs).

Reviewer 2:

This reviewer referenced “Development of Thin, Robust, Lithium-Impenetrable, High-Conductivity, Electrochemically Stable, Scalable, and Low-Cost Glassy Solid Electrolytes (GSEs) for Solid State Lithium Batteries,” and asserted that the presentation is very clear and very well organized with clear milestones. The project seems to have met the milestones for 2019 and 2020. The remaining challenges are well defined, and a clear path forward is set.

Reviewer 3:

Well-designed work starting with GSE composition development was observed by this reviewer, followed by thin film forming and finished by assembling asymmetric and symmetric cells LM|GSE|SS for stability testing and cycling.

Reviewer 4:

The reviewer explained that glass technology has a significant technical and economic potential for solid electrolyte Li metal batteries. The compositional space affords flexibility and opportunities to design for a range of metrics. Regarding the approach, it seemed to this reviewer that some industrial partnerships could help. Why not partner with a glass company who could provide the type of engineering and technician support for the glass draw? The reviewer could imagine that getting that equipment up and running, and getting students trained and operating a piece of equipment like that is both challenging and requires a significant period of time.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

This reviewer commented that the team has demonstrated several technical accomplishments and progress in the overall project. The project is in a great shape in terms of milestones and publications. Stability of the new electrolyte is well characterized in respect to temperature, air exposure, and operating potential window. The reviewer explained that what is missing is more insights into chemical stability of the electrolyte in contact with metallic Li. Looks like observed interfacial reactivity is self-limiting and beneficial resulting in increased electronic resistivity and decreased interfacial resistivity. Because dramatic change in SEI resistivity is already observed in contact with Li disk even without external pressure applied, this reactivity will be amplified with evaporated Li and should be carefully characterized. The reviewer further suggested that evolution of interfacial layer/reactivity upon electrochemical cycling should be followed.

Reviewer 2:

Project milestones for 2019 and 2020 seemed to have been met from this reviewer's perspective, and the milestones were clearly indicated in the results section. This reviewer offered additional questions and/or comments about the presentation.

Referencing Slide 8, the reviewer asked if there are any other characterization methods to assess stability with air. Would it be possible to say something about the mechanism of ionic transport that is in these materials (GSE)? Weak electrolyte or strong electrolyte? Any anisotropy effects in these materials, due to processing? Need to make sure that the properties of GSE are uniform across the film to warrant cell to cell reproducibility.

Concerning Slide 9, this reviewer reported that impedance plots show stability. More comments on the actual magnitudes of the impedances on the slides would be very welcome. Are they high?

Regarding Slide 11, the reviewer inquired about whether it would be possible to elaborate a little more on why liquid electrolyte is being adding. Would the liquid electrolyte deplete with time/cycling? The reviewer also referenced stability test goals for high voltage (full cell). Why LFP?

Highlighting Slide12, the reviewer asked why the efficiency increases with cycling.

Reviewer 3:

The reviewer stated that the project team has all milestones for FY2020, but no progress report for the first quarter of FY2021. The project team's targeted stability with LM anode did not seem impressive—100 cycles with less than 20% degradation. However, the team has done a good job in the composition development of GSE.

Reviewer 4:

The presenter showed several compositions, and different compositions are used, in some cases this reviewer believed, to report against different milestones. A single composition should be compared against all of the milestones.

The reviewer observed "very modest" cycling performance as the presenter stated, but the reasons for this are not clear. It would be very helpful for the presenter to share some failure analysis for the samples. Otherwise, the audience is left wondering about the huge gap between the potential for glass SE technology and the demonstrated performance in a battery.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

Although there are no collaborations with other institutions so far, this reviewer indicated that new collaborations are planned. The topics selected for the collaboration are well defined.

Reviewer 2:

This reviewer observed no partners so far; however, new partnerships are programmed.

Reviewer 3:

No collaboration currently exists, but the reviewer opined that planned collaboration with ORNL on Evaporated Lithium on ISU GSEs to investigate LM/GSE interface and cycling performance will be excellent addition to this project. This reviewer recommended collaborating as well with someone doing DFT calculations as this might help to explain the chemistry a little better.

Reviewer 4:

As previously mentioned by this reviewer, there are no partners formally on the project, and it seems the PI is pursuing a "go-it-alone" approach. This is likely to be very slow, and not draw on the expertise of others to overcome challenges.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

A Clear path toward full cell assembly and characterization was noted by this reviewer.

Reviewer 2:

This reviewer stated that proposed future work is in-line with the project needs and should improve the performance of the GSE proposed in this project. New challenges might arise from the optimization process, given inter-dependence of the different parameters.

Reviewer 3:

The reviewer indicated that the important areas to work on are listed in future work. However, there is a question about how much progress a single PI at a university can make on a project like this within a few years.

Reviewer 4:

The reviewer described the project team's future tasks on GSE composition optimization and thin-film forming as well planned. The team has more work to do in cell forming and testing, which should be its first priority.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer commented that "Development of Thin, Robust, Lithium-Impenetrable, High-Conductivity, Electrochemically Stable, Scalable, and Low-Cost Glassy Solid Electrolytes (GSEs) for Solid State Lithium Batteries" is certainly in-line with DOE mission and objectives. The development of new materials at a competitive cost for energy storage is greatly needed and supports the overall DOE objectives.

Reviewer 2:

GSE is an important part to make the all-solid-state-battery (ASSB), which this reviewer stated is currently one of the main approaches in making better LIBs. The project supports the DOE objective to promote electric drive vehicles.

Reviewer 3:

This reviewer asserted that the project supports main DOE goals—high conductivity, stability to air, industrial scale processing.

Reviewer 4:

Glass solid electrolyte technology has very good potential from this reviewer's perspective.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

This reviewer stated that the PI already seems to have the necessary equipment and expertise to carry on with the project. Materials cost and manpower seem to be covered with the current level of funding.

Reviewer 2:

Resources and expertise seem sufficient to achieve proposed milestones from this reviewer's perspective.

Reviewer 3:

The reviewer observed the team has sufficient technical resources in making the proposed GSEs, although the team probably needs help via collaboration in cell testing.

Reviewer 4:

The reviewer remarked that the project spans glass composition development, battery making and evaluation, and glass draw. A single PI doing this with students at a university is not sufficient resourcing to make significant progress.

Presentation Number: bat479
Presentation Title: Composite Solid Ion Conductor with Engineered Lithium Interface
Principal Investigator: Kyler Carroll (Wildcat Discovery Technologies)

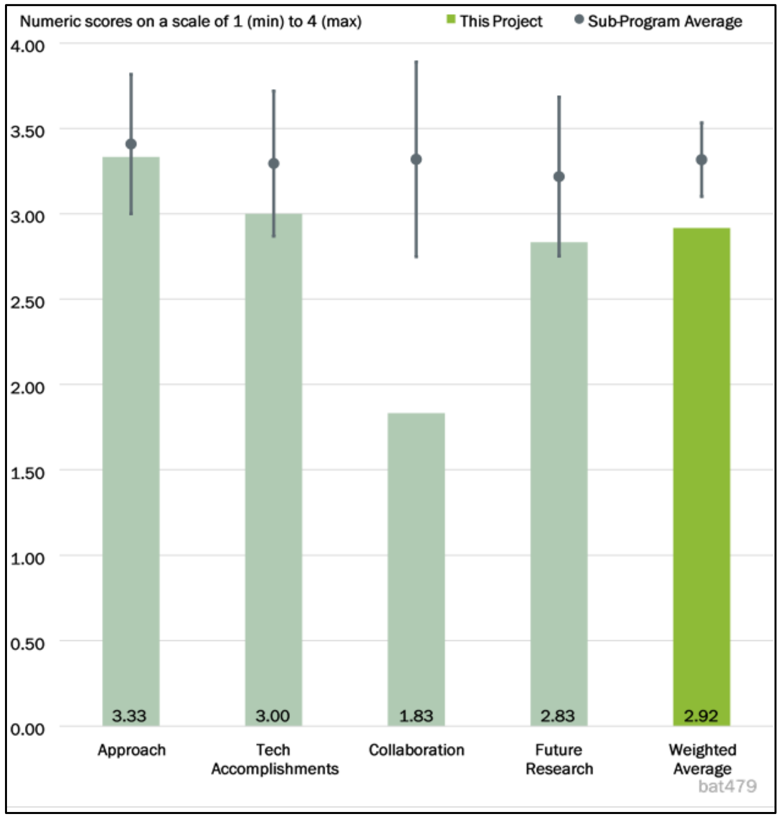


Figure 2-35 - Presentation Number: bat479 Presentation Title: Composite Solid Ion Conductor with Engineered Lithium Interface Principal Investigator: Kyler Carroll (Wildcat Discovery Technologies)

Presenter

Kyler Carroll, Wildcat Discovery Technologies

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 17% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer remarked that Wildcat is very good at developing approaches for high throughput screening. The reviewer mentioned that the approach for screening the catholyte is good, but was not so sure about using a liquid to screen the protected lithium anode interface. The reviewer added that the project team's overall approach of finding a surface stabilizing treatment of the anode and developing a high voltage polymer/inorganic solid conductor composite for the cathode, is a good one.

Reviewer 2:

The reviewer stated that the work approach has enabled the evaluation of greater than 5000 variations, and that the trilayer approach enabled a quick metric to determine promising interfacial treatments.

Reviewer 3:

The reviewer said that testing and optimizing many different materials is a terrific approach to improving battery performance.

Reviewer 4:

The reviewer stated that the PI uses two approaches for improving solid state battery performance: solid electrolyte optimization and lithium metal protection. The reviewer remarked that for the solid electrolyte, the PI uses surface-treated inorganic ceramics to be integrated with polymers in forming composite electrolyte that shows balanced performance in ionic conductivity, mechanical and electrochemical stability, and interfacial contact. The reviewer added that for lithium metal protection, the PI uses coating on lithium metal anode to suppress dendrite formation. The reviewer wrapped up by acknowledging that these approaches are in line with the state-of-the-art understanding of the key challenges facing solid state batteries.

Reviewer 5:

The reviewer mentioned that developing polymer ceramic composite electrolytes helps to improve the interfacial contact between electrolyte and electrodes including both Li metal anode and high voltage cathode. The reviewer added that there are also some key challenges:

- Organic components are typically not chemically stable with Li metal and 4-volt (V) cathodes. Thus, this approach usually introduces interface resistance in this regard.
- The ionic conductivity of composite electrolyte without a liquid component is low.
- It is still an open question whether the composite electrolyte performs better to suppress dendrite formation than inorganic solid electrolytes.

The reviewer said that this project aims to address some of the key challenges by screening the ceramic electrolyte, polymer electrolyte (in the bulk electrolyte layer and in the cathode composite), and interfacial layer on Li metal. The reviewer stated that it is not clear whether the study on SEI formation from liquid electrolytes is necessary and can be transferred to the interlayer design in this project. The reviewer expressed that there are already a large number of published results to reveal the composition and structure of SEI formed in liquid electrolyte batteries.

Reviewer 6:

The reviewer stated that although “mechanically stable interfaces” is one of the objectives, the project does not have any quantitative criteria for and measurements of interfacial mechanical stability. The reviewer added that SSE target properties, such as greater than or equal to 8.4 gigapascal (GPa), Lithium compatibility “stable”, and processability “standard” are ill-defined.

*Question 2: **Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.***

Reviewer 1:

The reviewer stated that the work to improve the interface revealed promising approaches to reduce the impedance. The reviewer added that the ability to protect the Li and also protect the electrolyte from reduction is an important accomplishment enabling more design flexibility.

Reviewer 2:

The reviewer said that surface treatment is shown to greatly reduce or even eliminate the interfacial resistance between the inorganic component and the polymer component in the solid electrolyte. The reviewer added that the PI has identified chemical approaches (formula not specified probably because it is proprietary information) to protect the lithium metal anode. The reviewer noted that composite electrolyte and lithium anode protection enable a solid-state battery cell that delivers around 180 mAh/g capacity in the voltage range of 4.3V-3V for around 20 cycles. The reviewer mentioned that the composite electrolyte showed ionic conductivity in the order of 10^{-5} Siemens per centimeter (S/cm) which needs some improvement, and that the mechanical stability of the composite electrolyte may also need to be strengthened.

Reviewer 3:

The reviewer stated that the ionic conductivity of around 10-5 S/cm was achieved by compositing $Li_{1.3}Al_{0.3}Ti_{1.7}(PO_4)_3$ (LATP) with a polymer. The reviewer added that the ionic conductivity is not high compared with data available in the public literature, and that further efforts should be done to improve the ionic conductivity. The reviewer mentioned that LATP is not stable with Li metal, and questioned whether an interfacial layer between LATP and Li can effectively suppress the reaction between LATP and Li. The reviewer thought the solid-state full cell is still run at a low rate of 0.05C at 60°C.

Reviewer 4:

The reviewer stated that the project team makes excellent progress compared to their base case. However, the reviewer pointed out that the team does not compare its best results to what others have already achieved, and the reviewer sees no evidence that the team's results are better than the best previously reported results.

Reviewer 5:

The reviewer stated that a negative interface resistance is non-physical. The reviewer could not evaluate the accomplishments based on the code names—A, B, C, ..., and M for the additive families. The reviewer questioned what the discovered "chemistry trends" are that can be used to seek further improvements.

The reviewer noted that the mechanical strength measurement method, e.g., tensile or compression, should be disclosed. The reviewer added that the decreasing Young's modulus with increasing inorganic content is counter intuitive based on the upper- and lower-bound estimates for the elastic modulus of ceramic-polymer composites. The reviewer mentioned that the Young's modulus and yield strength values for the composite solid electrolytes are too low—much below the 8 GPa modulus target.

Reviewer 6:

The reviewer noted that it is hard to measure the accomplishments of this project as there is not much discussion on C-rate or capacity per cm^2. The reviewer stated that there is no mention of addition of carbon to the cathode, and finally, with just 20% of the project left, there is no discussion of full cell cycleability, which is the hardest thing to accomplish with this chemistry.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted that the project was 20% funded by Wildcat, which is trying to develop intellectual property (IP). So, it is of little surprise that the project team does not have collaborators.

Reviewer 2:

The reviewer stated that only one company was involved.

Reviewer 3:

The reviewer remarked that the project team does not have partners.

Reviewer 4:

The reviewer noted that the project team stated that there are no collaborators.

Reviewer 5:

The reviewer observed that the PI indicated that no collaboration is involved, but that this is due to proprietary concerns.

Reviewer 6:

The reviewer encouraged the project team to collaborate with other institutions on this project.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer stated that an appropriate path forward was outlined.

Reviewer 2:

The reviewer mentioned that the degradation mechanism of the full cell performance will need to be studied to identify the component that leads to cell failure. The reviewer added that the interfacial resistance may not be the only and the main reason for cell degradation. The reviewer suggested that the project team should also consider dendrite formation as one reason for full cell failure, as some full cells are clearly shorted by dendrite formation.

Reviewer 3:

The reviewer stated that the PI has proposed future research in further optimizing composite electrolyte, especially in improving the mechanical strength. The reviewer noted that the PI also proposed further research in lithium metal anode protection and has already made some progress in the project but indeed needs further improvement.

The reviewer suggested that the PI can consider further improving the ionic conductivity of the composite electrolyte as mentioned in previous comments. The reviewer encouraged the PI to also consider increasing the current density used in testing the solid-state battery cell—it is now 0.06 mA/cm^2 which may be too low.

Reviewer 4:

The reviewer remarked that the proposed future research is vague and does not have quantitative measures and goals to “Optimize incorporation of the SSE (catholyte) into the cathode” and to “Further reduce resistance between SSE and coated lithium.”

Reviewer 5:

The reviewer noted that the project team is still screening surface agents, and that it is not clear the team will be able to make a decent cell by the end of the program. The reviewer added that the project team is not sharing what it learned.

Reviewer 6:

This reviewer indicated that proposed future work is sensible, and there is promise.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer noted that this project supports the overall DOE objectives in providing clean energy solutions. The reviewer added that specifically, the beyond Li-ion battery option has higher energy density and better safety characteristics than the conventional liquid electrolyte-based Li-ion batteries.

Reviewer 2:

The reviewer stated that if successful, the work could play a role to lower cost on a $/kWh—an important metric for the DOE.

Reviewer 3:

The reviewer mentioned that the DOE would like to see an advancement in solid state batteries as they offer high energy density.

Reviewer 4:
The reviewer agreed that the project supports the overall DOE objectives.

Reviewer 5:
The reviewer stated that yes, the project enables the utilization of lithium metal anode for high-energy density batteries.

Reviewer 6:
The reviewer remarked that better solid-state batteries is the goal.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:
The reviewer stated that the project is right on target and amount of funding.

Reviewer 2:
The reviewer mentioned that the resources for the project are sufficient to achieve the stated milestones in a timely fashion.

Reviewer 3:
The reviewer noted that the project team has sufficient resources.

Reviewer 4:
The reviewer declared that the project has the adequate resources.

Reviewer 5:
The reviewer noted that the resources are sufficient as they match what Wildcat was willing to put forward. The reviewer added that Wildcat will have a better understanding of the difficulties of this chemistry and possible paths forward when the project concludes.

Reviewer 6:
The reviewer mentioned that the project team does not seem to have the capability to quantify "Mechanically stable interfaces."

Presentation Number: bat480
Presentation Title: Physical and Mechano-Electrochemical Phenomena of Thin Film Li-Ceramic Electrolyte Constructs
Principal Investigator: Jeff Sakamoto (University of Michigan)

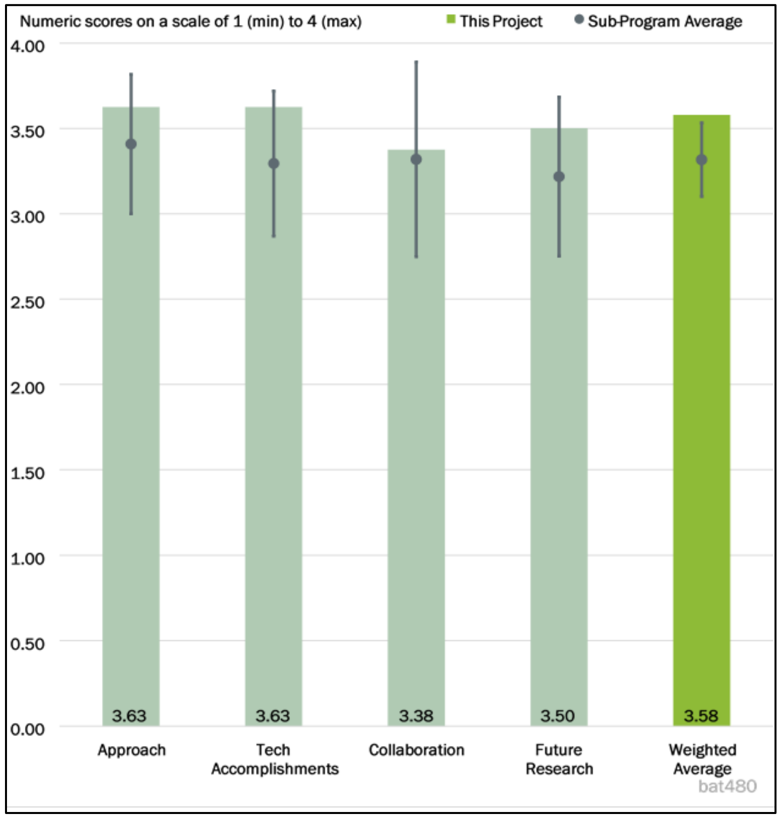


Figure 2-36 - Presentation Number: bat480 Presentation Title: Physical and Mechano-Electrochemical Phenomena of Thin Film Li-Ceramic Electrolyte Constructs Principal Investigator: Jeff Sakamoto (University of Michigan)

Presenter

Jeff Sakamoto, University of Michigan

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that the work was excellent. The reviewer added that it is critical that the battery scientific community starts to understand and account for the differences in material and cell properties when using non-commercial type materials, like very thick Li or very thick solid electrolytes. The reviewer declared that it is excellent that Professor Sakamoto is doing a comprehensive study of the impacts of thickness, pressure, and current density on the stripping and plating of Li metal. The reviewer encouraged the project team to quickly incorporate studies of very thin LLZO electrolyte. The reviewer suggested that the large differences seen in behavior between thick (700 micron) and thin (20 micron) Li metal could be equaled or exceeded by changes seen in the behavior of cells using thick and thin LLZO. The reviewer noted that Professor Sakamoto correctly pointed out the radically different mechanical property of traditional glass sheets and the much thinner glass used in optical fibers.

The reviewer commented that the Battery500 program has found that pressure can extend Li metal (liquid electrolyte) cell cycle life by two times, and mentioned that understanding the quantitative role that pressure plays in Li metal cells could be critical.

Reviewer 2:

The reviewer stated that the approach of this project, as performed by Sakamoto and co-workers, aims to bridge fundamental and applied battery research in order to better understand how SSB designs (and packaging) affect the overall performance, especially with Li metal anodes. The reviewer noted that the main technical barriers addressed in this project are 1) performance (e.g., enabling Li metal anodes to achieve greater than 1000 Watt-hour per liter (Wh/L) and 2) cost (e.g., enabling Li free manufacturing to achieve less than $100/kWh). The reviewer declared that the first approach includes operando visualization analysis of in situ Li metal growth on Li garnets, while the second approach includes studying the stripping behavior of thin Li (e.g., thickness of 10 microns). The reviewer concluded that overall, this systematic approach has a great impact on the SSB community, as the plating behavior of thin and thick Li is drastically different and can also influence the cycle life of full SSB cells.

Reviewer 3:

The reviewer said that operando cell allows direct visualization of the lithium behavior upon plating and stripping, under different pressures. The reviewer remarked that it is a nice design and will facilitate the fundamental understanding of thin lithium.

Reviewer 4:

The reviewer stated that the integration of thin Li anode is important to further improve the energy density of SSBs. The reviewer mentioned that this project evaluated the Li plating/stripping behaviors in operando and observed the stacking pressure effect on the Li nucleate morphology. The reviewer added that the project provides knowledge from the anode side to address long term stability issue of SSBs.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that the project "Physical and Mechano-Electrochemical Phenomena of Thin Film Li-Ceramic Electrolyte Constructs" reports a number of important technical accomplishments. The reviewer added that the project 1) provides important insight towards in situ Li anode formation, 2) highlights structure-property relationships of the Li metal/Li garnet interfaces, 3) compares the impact of thick versus thin Li metal, and 4) discusses the overall mechanical behavior of commercially-relevant Li metal thicknesses (10-20 microns). The reviewer explained that while these technical accomplishments are impressive, more attention should be given to approaches that prevent de-wetting of Li metal anodes, especially approaches that may overcome the apparent need to have relatively high stack pressures. The reviewer concluded that special attention should be given to the proposed solid-state Li-S prototypes.

Reviewer 2:

The reviewer noted that the project mainly focused on the fundamental understanding of thin lithium behaviors, but not the device performance. For example, it was not clear how far it is from the technology readiness level (TRL) 6 project goal.

Reviewer 3:

The reviewer said that the project team gained knowledge of the Li plating/stripping behaviors in a Li/LLZO/Cu. The reviewer added that this information will guide future adoption of methods for better utilization of Li reversibly. The reviewer noted that it is not clear what tools will be evaluated in future work to address the issue.

Reviewer 4:

The reviewer stated that the work was excellent, and that very good progress has been made toward goals. The reviewer was a bit nervous about conclusions being drawn using very thick LLZO. The reviewer understood the practice issues with obtaining thin (20 micron) and defect free LLZO, but felt like that should become a priority soon.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer mentioned that the project team appears to have close, appropriate collaborations as well as coordination with the PI's startup, Zakuro Inc. The reviewer added that this project also includes important collaborations within the lead PI's home institution, the University of Michigan. The reviewer concluded by saying that overall, the work and the team appear to be well coordinated by the PI.

Reviewer 2:

This reviewer had no comments.

Reviewer 3:

The reviewer stated that it was not clear how the team collaborates with the partner Zakuro Inc.

Reviewer 4:

The reviewer questioned what Zakuro Inc. contributes to this project, and encouraged more collaborations across project teams.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer stated that future work looks good.

Reviewer 2:

The reviewer mentioned the PI listed very clearly the future research directions. The reviewer commented that addressing the void formation/dewetting issue is critical for the adoption of Li-free or thin Li anode.

Reviewer 3:

The reviewer stated that the project "Physical and Mechano-Electrochemical Phenomena of Thin Film Li-Ceramic Electrolyte Constructs" will end on September 30, 2022, and is approximately 50% complete. The reviewer added that the proposed future work includes further work with "Li free" manufacturing; further work with cycling thin Li metal anodes (presumably between 10-20 microns in thickness); work with cathode integration (e.g., Li-S batteries); and a continuation to link project findings with vehicle electrification needs. The reviewer suggested that while these four areas are incredibly important, special attention should be given to approaches to prevent de-wetting during Li metal stripping. The reviewer noted that overcoming this hurdle can significantly improve the utilization of thin Li metal anodes in batteries with specific energies greater than 350 Wh/kg.

Reviewer 4:

The reviewer said that Professor Sakamoto seemed to agree that studying behavior using commercially relevant LLZO thicknesses was critical although the reviewer did not see this mentioned in the project's future plans.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer stated that it is highly relevant.

Reviewer 2:

The reviewer mentioned that this project has strong relevance to DOE. The reviewer added that the objective of this project is to overcome the performance and cost barriers associated with all-solid-state batteries by specifically understanding the physical and mechano-electrochemical phenomena at solid-solid interfaces. The reviewer noted that these results have direct implications to the electric vehicle market. The reviewer remarked that this project aims to provide a far-reaching understanding of how thick Li (e.g., thickness greater than 50 microns) and thin Li (e.g., thickness 10-20 microns) perform in all-solid-state batteries. The reviewer commented that these results have far-reaching implications for practical cells that will most likely use only 10-20 microns of Li.

Reviewer 3:

The reviewer stated that this research focuses on decreasing the thickness of lithium metal anode, which is critical for solid-state battery.

Reviewer 4:

The reviewer said that one of DOE's objectives is to improve energy density and safety of battery technology. The reviewer mentioned that this project, if successful, will enable the use of thin Li or Li-free anode for solid state batteries, which can further improve the energy density and increase battery life.

Question 6: ***Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?***

Reviewer 1:

The reviewer remarked that the project team was able to meet most of its proposed milestones despite COVID-19. The reviewer added that the team has the proper equipment and resources to carry out this research, and has a number of active collaborations both internally (through the University of Michigan) and externally (with Zakuro, Inc.). The reviewer noted that the team has expertise in thin film coatings, and has the resources to complete work related to exploring possible approaches to prevent de-wetting during Li metal stripping (e.g., possibly an interlayer). The reviewer concluded that overall, the project team completed great work despite setbacks from COVID-19 and met most of its milestones to date.

Reviewer 2:

The reviewer commented that the resources at the University of Michigan are great.

Reviewer 3:

The reviewer noted that the funding level is sufficient to conduct the proposed experimental work.

Reviewer 4:

The reviewer remarked that funding should increase, if possible, and the scope of work needs to be expanded.

Presentation Number: bat481
Presentation Title: Li Dendrite-Free Li7N2I-LiOH Solid Electrolytes for High Energy Lithium Batteries
Principal Investigator: Chunsheng Wang (University of Maryland, College Park)

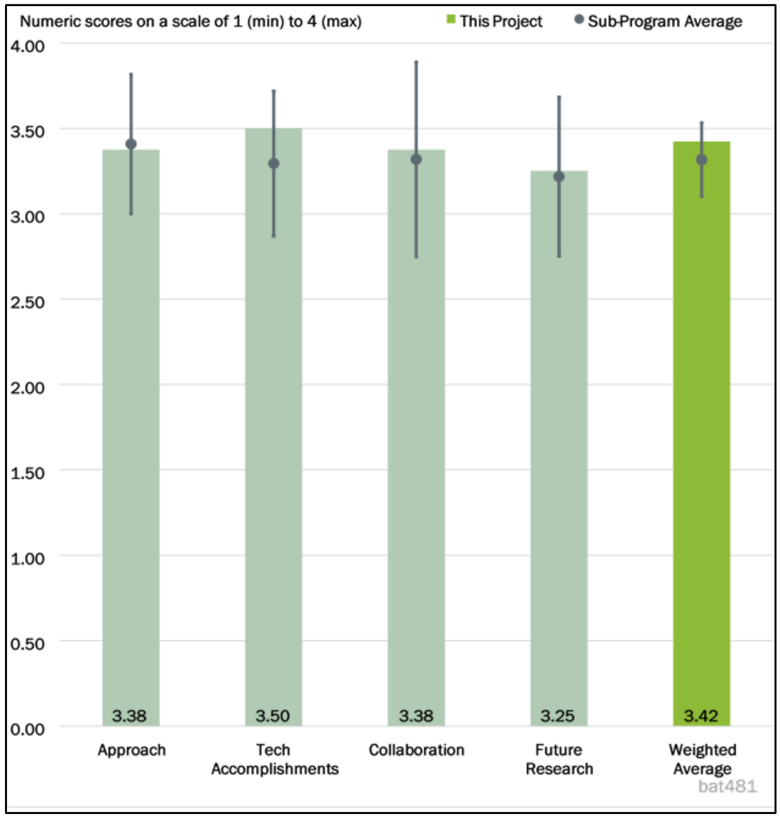


Figure 2-37 - Presentation Number: bat481 Presentation Title: Li Dendrite-Free Li7N2I-LiOH Solid Electrolytes for High Energy Lithium Batteries Principal Investigator: Chunsheng Wang (University of Maryland, College Park)

Presenter

Chunsheng Wang, University of Maryland, College Park

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that the project team developed several techniques to address the Li-anode/electrolyte interface problems. The reviewer added that the team developed doped Li-M alloy to enhance diffusivity at the SSE interface, and several interface layers to suppress Li dendrite growth. The reviewer noted that the electrochemical tests show promising interfacial stability.

Reviewer 2:

The reviewer mentioned that the project team developed great work and publications. The reviewer remarked that the idea of mixing lithiophobic and lithiophilic electrolytes to try to prevent Li dendrite growth while maintaining good ionic conductivity, is worth pursuing. The reviewer questioned whether this approach is really preventing Li growth or just delaying it. The reviewer commented that Li can eventually find a path via the lithiophilic phase.

Reviewer 3:

The reviewer stated that there was a good outline for the plan, but that it was somewhat limited in scope.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer mentioned that the LiF-C-LixM interlayer with mixed ionic/electronic conductivity shows good capacity retention at up to 450 cycles.

Reviewer 2:

The reviewer stated that the project is moving forward and is on target, with several good results presented. The reviewer added that the approach seems to provide some improvements with respect to performance. The reviewer noted that more microscopic characterizations might be needed to show dendrite mitigation and improved interface.

The reviewer posed a few questions about the presentation. Regarding Slide 6, the reviewer asked whether the project team can provide some details on how magnesium (Mg) addition into Li increases the Li diffusivity? If so, what is the mechanism of Li diffusion within the alloy? Additionally, the reviewer explained that alloying Li with Mg impacts some other mechanical properties. Which property is important for this system, mechanical or Li diffusivity (if really changed)?

Regarding Slide 7, the reviewer inquired about the experimental data that supports the density functional theory (DFT) results—"Li reservoir during cycling without Li-metal formation"? The reviewer asked whether high interface energy (lithiophobic electrolyte) and Li-ion conductivity are antagonistic, resulting in the need to mix-in a lithiophilic electrolyte.

This reviewer inquired about the property that was calculated to reach the conclusion on Slide 9—"First-principles calculation indicates Li_7N_2I-LiOH is stable against Li metal."

Referencing "Lithiophobic-lithiophilic gradient & ionic conductive LiF-LixMg interlayer" on Slide 11, the reviewer asked if the Li-Mg alloy is stable with Li and with the lithiophobic Li fluoride (F) phase? Are there any theoretical calculations or experimental evidence?

Reviewer 3:

The reviewer stated that the project team has demonstrated several technical accomplishments and showed progress in the overall project. The reviewer mentioned that the project is in good shape in terms of milestones and publications. The reviewer remarked that the team developed in-situ formation of a mixed electronic/ionic conductive and lithiophobic-lithiophilic gradient layer between Li and solid-state electrolyte to suppress Li dendrite growth.

The reviewer posed the following questions:

- Is the cycling necessary to form this lithiophobic-lithiophilic gradient or can it be formed with heating as well?
- Is there separate precondition cycling step that is required for the creation of this interlayer or is it happening during the first cycle?
- Is dimethyl ether (DME) liquid electrolyte completely decomposed/evaporated at the interface during cycling?
- How thick is the whole interface layer if LiF alone is approximately 200 nanometers (nm)?
- Can the thickness be further minimized with all three components preserved?
- Has the project team tried a liquid electrolyte mix without $Mg(TFSI)_2$?

- Can porous and approximately 200nm thick LiF alone protect $Li_{10}GeP_2S_{12}$ (LGPS) and serve as Li reservoir during cycling?
- What is the difference in dendrite protection by in-situ-formed LiF compared to pressed solid powder?
- When the 200-micron thick lithiophobic porous LiF-lithium nitride (Li_3N) electrolyte was used as interlayer for Li dendrite suppression, Li was penetrating approximately 10 microns deep. Is that saying that the lithiophobic component is critical for design of effective thin interlayers?

The reviewer concluded by stating that the formation process can be followed with EIS, and suggested that the role of each of the lithiophobic and lithiophilic component on the interfacial resistivity should be studied.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer mentioned there are good and effective collaborations with national laboratories and industry.

Reviewer 2:

The reviewer remarked that there is little collaboration apparent so far, but noted that the collaboration with the National Institute of Standards and Technology (NIST) and BNL is a good direction.

Reviewer 3:

The reviewer stated that there was good collaboration, but it was not clear from the presentation how much contribution was in fact present. The reviewer added that there were good and appropriate characterization techniques from two of the listed collaborators, but that the project team should better support the claims presented in this work.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer stated that the project team is aware of the critical remaining challenges, and that it proposed future research that includes mechanical property improvement and incorporating the SSE/interphase to the NMC811 and Li_2S cathodes.

Reviewer 2:

The reviewer said that there was clear work proposed towards dendrite/critical current density (CCD) investigation but was unclear about cathode side protection.

Reviewer 3:

The reviewer observed that the proposed future work is certainly in line with the project, but that at the same time it was a little generic and mainstream. The issues to solve and phenomena set to understand are the issues the research community is striving to solve. The reviewer suggested that more specific and achievable goals would serve the project better.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that the development of high-energy rechargeable Li metal all-solid-state batteries for future vehicle electrification is part of the DOE objectives.

Reviewer 2:

The reviewer mentioned that the development of new stable solid-state electrolytes will support the overall DOE objectives, and noted that new approaches such as the one presented in this work are worth pursuing.

Reviewer 3:

The reviewer commented that this project clearly adds to the understanding of the correlation between Li dendrite formation and the intrinsic properties of solid-state electrolytes such as lithiophobicity, solid electrolyte interphase, porosity, thickness, and ionic and electronic conductivity.

*Question 6: **Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?***

Reviewer 1:

The reviewer said that the project team has strong capabilities and technical resources to accomplish the project.

Reviewer 2:

The reviewer stated that the resources seem to be sufficient to cover extra materials and research needed for this project.

Reviewer 3:

The reviewer remarked that the resources and expertise seem sufficient to achieve proposed milestones.

Presentation Number: bat482
Presentation Title: Hot Pressing of Reinforced Lithium Nickel Manganese Cobalt Oxide (Li-NMC) All-Solid-State Batteries with Sulfide Glass Electrolyte
Principal Investigator: Thomas Yersak (General Motors, LLC)

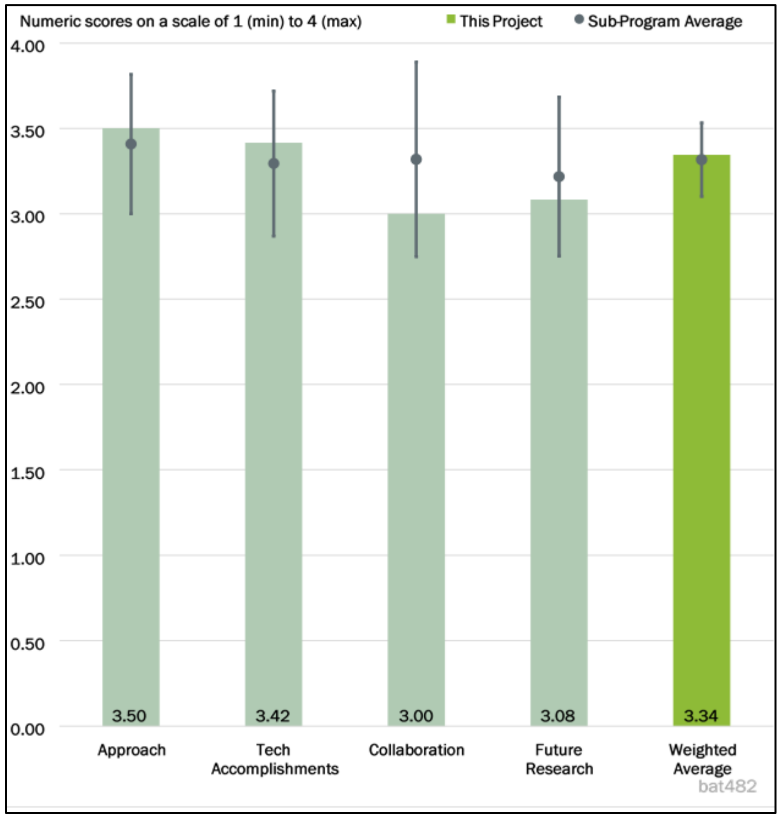


Figure 2-38 - Presentation Number: bat482 Presentation Title: Hot Pressing of Reinforced Lithium Nickel Manganese Cobalt Oxide (Li-NMC) All-Solid-State Batteries with Sulfide Glass Electrolyte Principal Investigator: Thomas Yersak (General Motors, LLC)

Presenter

Thomas Yersak, General Motors, LLC

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that the approach is sound for R&D, and that it is good to see a study of cathode/SSE optimization.

Reviewer 2:

The reviewer said that the approach is to use hot pressing of glasses to reduce porosity and hence improve energy density, which seems like a reasonable approach. The reviewer added that since high temperature may lead to decomposition, the project team will look for additives to stabilize the electrolyte.

Reviewer 3:

The reviewer said that being able to hot-press sulfide-cathode composites using realistic pressures is a critical barrier to enabling ASSBs. The project is well-thought-out in terms of aiming for practical applications.

Reviewer 4:

The reviewer noted that the PI applies General Motors' (GM) hot-press technology to combine coated NMC and glass electrolyte together, in an effort to form a catholyte with reduced porosity and hence increased energy density. The reviewer remarked that such a feasibility test is needed for the possible application of hot-press in solid state batteries, especially from the industry point of view.

Reviewer 5:

The reviewer stated that it is highly questionable whether the objective of eliminating porosity in the cathode is achievable or even beneficial since some level of porosity may help accommodate the volume change of the positive electrode materials during electrochemical cycling. The reviewer commented that since NCM microcracking is likely caused by both thermal and diffusion induced stresses, the project should include approaches to address both, as opposed to just one (thermal).

Reviewer 6:

The reviewer affirmed that hot pressing cathode composite certainly helps to improve the physical contact between solid electrolytes and electrodes. The reviewer added that the possible sintering of solid electrolyte would also increase the ionic conductivity of solid electrolyte, which will also contribute to the kinetic performance of the cell. The reviewer commented that the main challenge would be how to mitigate the chemical stability between the cathode and solid electrolyte at elevated temperatures. The reviewer thought that the team is well aware of the challenge and proposed a detailed study on thermal stability.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer said that this work does an outstanding job trying to deeply understand all of the features that were observed, such as how porosity is affected by component properties, how cracking occurs, how ionic conductivity is affected by hot pressing, and even identifying a new phase in the catholyte. The reviewer noted that this work also incorporates and takes advantage of an understanding of glass short range structure.

Reviewer 2:

The reviewer mentioned that the PI was able to look at variations on the catholyte and found one that works considerably better than others. The reviewer noted that the density was improved, and that there was relatively good charge/discharge demonstrated. The reviewer remarked that the lithium bromide (LiBr) addition strongly improves the performance and is a promising result.

Reviewer 3:

The reviewer stated that the project team showed that beta-Li_3PS_4 reduces the differential scanning calorimetry (DSC) heat overall and does not require coatings for improvements. The reviewer noted that the Li_6PS_5Cl does require a protective layer to reduce reaction with the cathode active material. The reviewer added that that hot pressing does reduce the porosity, but results in a loss of capacity if the cathode material is not protected. The reviewer remarked that the addition of carbon black can reduce the microcracking seen with high temperature pressing, but can lead to more surface reaction. The reviewer said that the project team selected a catholyte combination that includes hot pressing, and that the team has shown progress throughout.

Reviewer 4:

The reviewer stated that the project team identified the optimized mixing process for the cathode composite and demonstrated that the hot-pressed cathode showed better cycling performance than the cold-pressed one. The reviewer added that the team also did a comprehensive investigation on the thermal stability between cathode and electrolyte.

Reviewer 5:

The reviewer mentioned that the PI verified the possibility of utilizing cathode support for GM’s hot pressed, reinforced sulfide glass separators. The reviewer added that a full cell using NMC and sulfide based catholyte, sulfide electrolyte, and indium anode was demonstrated. The reviewer noted that hot-press did show the capability of decreasing the porosity in NMC cathode.

The reviewer remarked that indium, not lithium, is used as anode in the full cell testing, which suggests that the incompatibility between the sulfide electrolyte and lithium metal is not addressed. The reviewer stated that hot-press has some side effect such as partially damaging the NMC particles, and suggested that these areas need to be improved.

Reviewer 6:

The reviewer stated that the plasma-focused ion beam PFIB image on Slide 11 suggests poor utilization of the SSE particles because they are too large and do not form percolating paths for lithium-ion transport. The reviewer added that the "Processed image" on Slide 11 shows NCM particle cracking, but does not have sufficient resolution to show interface cracking between NCM and SSE particles. The reviewer said that the latter may be more detrimental to the degradation of the positive electrode.

The reviewer suggested that the project should explore the size and volume distribution of the SSE particles in the composite electrode. The reviewer remarked that the cycle life of the composite electrodes is quite poor (Slide 14). The reviewer proposed that this is likely caused by fracture at the interface between SSE particles and NCM particles due to volume change of the NCM particles. The reviewer recommended that the project should address this fundamental challenge that is inherent in all solid-state-batteries.

Question 3: ***Collaboration and Coordination Across Project Team.***

Reviewer 1:

The reviewer mentioned that the project seems well coordinated.

Reviewer 2:

The reviewer stated that external collaboration with researchers at Michigan Technological University and Iowa State University is planned.

Reviewer 3:

The reviewer mentioned that the project team is planning several collaborations.

Reviewer 4:

The reviewer stated that the PI collaborated with Michigan Technological University and Iowa State University.

Reviewer 5:

The reviewer noted that the existing data are mainly collected solely by the proposer, and that some collaborations with Michigan Technological University and Iowa State University are included in the plan.

Reviewer 6:

The reviewer noted some collaboration, but not much.

Question 4: ***Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.***

Reviewer 1:

The reviewer stated that the future proposed work and plan is appropriate.

Reviewer 2:

The reviewer mentioned that with the cathode chemistry and processing set, the project team will now turn to the separator processing. The reviewer noted that the team has reasonable goals.

Reviewer 3:

The reviewer mentioned that the project team has plans to greatly reduce the required pressure for hot-pressing.

Reviewer 4:

The reviewer stated that the PI proposed to limit the thickness of solid electrolyte to within 40 µm as future research, and carry out more specific test for the cell performance. The reviewer noted that both of these are indeed needed.

Reviewer 5:

The reviewer stated that the fundamental premise of eliminating porosity in the composite positive electrode is questionable because of the diffusion-induced volume changes and, consequently, stresses. The reviewer also remarked that the fracture at the interface between SSE and NCM particles, as well as the delamination at the interface between the composite electrode and the separator, should be addressed. The project should also explore the size and volume distribution of the SSE particles in the composite positive electrode.

Reviewer 6:

The reviewer said that it is expected that the side reaction between cathode and electrolyte highly depends on temperature. The reviewer suggested that the team should study the effect of temperature to identify the optimal temperature that can enable good interfacial contact, but avoid severe side reactions. The reviewer added that the mechanical stability of the hot-pressed cathode composite should also be carefully studied, as mechanical degradation such as contact loss and crack formation is one main reason for the limited cycling life of solid-state cathodes, even for the cold-pressed one.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer confirmed that this project supports the overall DOE objectives in providing clean energy solutions, specifically, the beyond Li-ion battery option that has higher energy density and better safety characteristics than the conventional liquid electrolyte-based Li-ion batteries.

Reviewer 2:

The reviewer said that this work supports the goal to achieve a higher energy density cell, which can lead to lower $/kWh.

Reviewer 3:

The reviewer stated that the project team is trying to develop an all-solid-state system, which is of interest to DOE.

Reviewer 4:

The reviewer remarked that the effort will enable safe, high energy density solid state batteries.

Reviewer 5:

The reviewer noted that the project is a good, new approach for enabling cost-effective ASSBs.

Reviewer 6:

The reviewer said yes.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

The reviewer stated that the program is funded appropriately.

Reviewer 2:

The reviewer stated that the project team has excellent resources.

Reviewer 3:

The reviewer said that the project team has good track record on solid-state battery development, and that it has sufficient resources.

Reviewer 4:

The reviewer remarked that a galaxy of high-quality technologies is being applied to this problem.

Reviewer 5:

The reviewer declared that the resources for the project are sufficient to achieve the stated milestones in a timely fashion.

Reviewer 6:

The reviewer mentioned that solid state is a challenging technology. The reviewer noted that the project team is making reasonable progress, but that there is no guarantee this will be successful.

Presentation Number: bat483
Presentation Title: Low Impedance Cathode/Electrolyte Interfaces for High Energy Density Solid-State Batteries
Principal Investigator: Eric Wachsman (University of Maryland, College Park)

Presenter

Eric Wachsman, University of Maryland, College Park

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

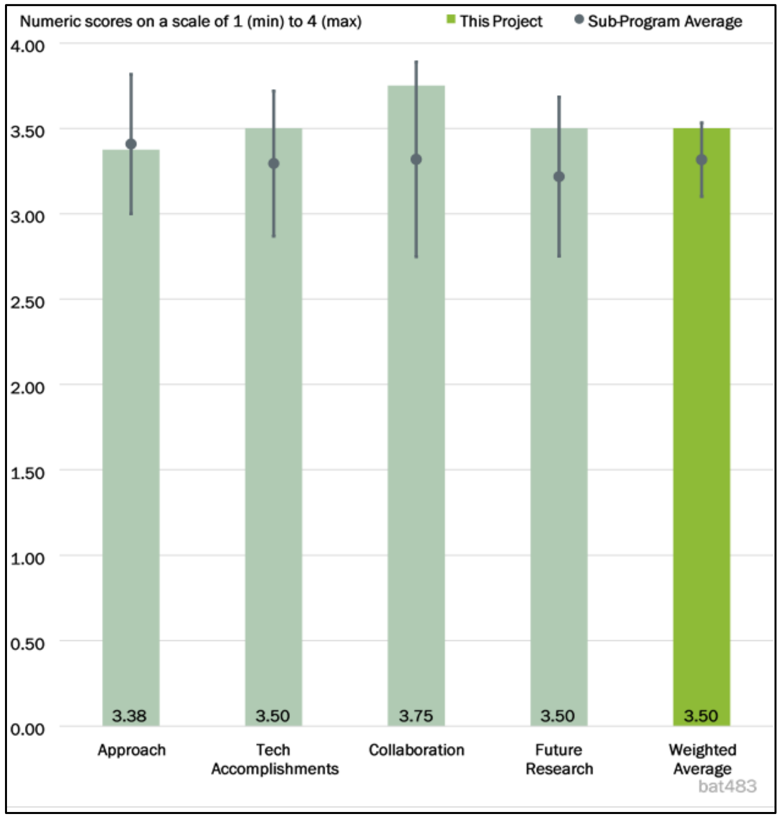


Figure 2-39 - Presentation Number: bat483 Presentation Title: Low Impedance Cathode/Electrolyte Interfaces for High Energy Density Solid-State Batteries Principal Investigator: Eric Wachsman (University of Maryland, College Park)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer stated that the project team's approach is systematic and builds on its demonstrated expertise with garnet-solid-state battery. The reviewer mentioned that the team proposes to first engineer interfaces to overcome high NMC/LLZ interfacial impedance and interfacial degradation. The reviewer continued that the team will then develop processing and fabrication techniques to achieve high loading NMC/LLZ composite cathodes with low resistance and high cyclability and integrate them into all-solid-state Li-metal/LLZ cells to achieve high energy density batteries.

Reviewer 2:

The reviewer said that the project team's approaches are concentrated in the NMC/LLZ interface. The reviewer stated that the team tries to add interphase by co-sintering the interface-coated LLZT/NMC cathode. The reviewer added that the team also adopts high-throughput computation to identify coating materials, and some advanced materials characterization techniques, such as X-ray tomography, to examine the effect of structure on performance.

The reviewer remarked that in general, these are proper approaches to the research objectives, however, the team needs better understanding on the NMC materials to find the proper conditions for sintering the interface layers.

Reviewer 3:

The reviewer stated that the presentation and the path forward were very clear, and that there were great results, both from the theory as well as from the preliminary experimental data.

The reviewer commented that the first project objective focusing on identifying interfacial layers to achieve low-impedance and stable NMC/LLZ interfaces relied on the results of DFT calculations of reaction energies between LLZ and NMC cathodes as well as potential coatings. The reviewer added that the calculations are based on known stable bulk compositions and assume complete reaction. The reviewer noted that this assumption provides a limit towards complete reaction of the reactants to the pre-defined products. The reviewer said that although they are a very good indicator of possible chemical reactivity of the components, the experimental results show possible phases at the interface not predicted by the model.

The reviewer stated that from XRD results $La_2Ni_{0.5}Mn_{0.5}O_4$ and $La_2Ni_{0.5}Co_{0.5}O_4$, seem to be the reaction products for all NMCs. The reviewer emphasized that there is no dependence on NMC composition, and that it is not present in the table of reaction products in the DFT screening results. The reviewer also stressed that for coatings, Li_2CO_3 seem to be a good candidate, and that there is then no need for complicated coatings.

The reviewer posed the following questions:

- How much delithiated NMC (d-NMC) is left?
- Can delithiation trigger instability within the cathode materials itself without even invoking the interface with lithium lanthanum zirconate (LLZO), i.e., decompose by itself?
- Can the project team provide more information about $LiNiO_2$ and $LiMnO_2$ results in the table? Have there been any reactions with LLZO?
- Regarding screening under voltage, how does one distinguish between 3V and 5V for LLZO? Does Li chemical potential change in LLZO?
- Supposing that 3V for NMC would correspond to a certain SOC and 5V to higher SOC, which NMC is used in the approach slide?
- In an earlier slide the project team mentioned more Mn leads to lower interfacial stability. In a later slide "Thermal Stability of LLZO with Different NMC Compositions," it is mentioned that, "the increase in Ni content increases NMC/LLZO reactivity." Does this mean that both Mn and Ni lower the interfacial stability?

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer said that starting with computational screening based on DFT for possible stable interfaces (solid state electrolyte, cathode, and cathode-coating), is helpful in eliminating obvious unstable compounds. The reviewer remarked that the DFT results are comprehensive within the proposed approach, and that the approach and calculations are simple and straightforward, but quite effective.

Reviewer 2:

The reviewer stated that the project team has reported results of calculations and materials characterizations. The reviewer added that the initial electrochemical test shows some effects of the interlayer, but the performance is far from the targeted standards.

Reviewer 3:

The reviewer noted that the campus was closed for three months due to COVID-19 and has only partially reopened, thus experimental results were limited resulting in a six-month no-cost extension (NCE). The reviewer added that the project team has demonstrated several technical accomplishments and progress in the overall project. The reviewer mentioned that the project is in good shape in terms of milestones and publications.

The reviewer stated that computationally and experimentally, the team determined the interfacial stability between LLZ solid electrolytes and NMC cathode and performed high-throughput computations of promising coating materials to determine appropriate compositions to stabilize the LLZ-NMC interface, guiding next stage experiments.

The reviewer said that the team demonstrated that percolating lithium film is necessary to enable low area-specific resistance (ASR) of the Trilayer. The reviewer added that the model indicated gradient porosity structure will perform better and the team fabricated gradient porosity structure and characterized by X-ray tomography.

The reviewer remarked that the team demonstrated interfacial layer that can stabilize LLZ-LCO interface to enable fast Li-ion transfer, but did not give more details on the interface layer chemistry or microstructure.

The reviewer noted that the team identified the elements and compositions with the widest stability range as promising coating candidates for interfacial stabilization. What is the desired thickness of an atomic layer deposition (ALD) coating? How does the team plan to address the mechanical damage and the formation of cracks, especially in the Ni-rich materials, due to large volume change during cycling? To be preserved, how thick can the coating be, if with poor ionic conductivity, to still be beneficial for overall cell performance?

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer stated that the project team collaborated with national laboratories and other universities in the US and Germany. The reviewer remarked that the collaboration is quite productive.

Reviewer 2:

The reviewer said that this team is a great example of collaborative experimental and computational work.

Reviewer 3:

The reviewer said that there is great collaboration between theory and experiment. The reviewer suggested that more feedback between the two could improve the overall understanding and outcome of the project. The reviewer noted that this last point is in fact mentioned in the future work already.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer remarked that the excellent future work plan focuses on interface design by coating, co-sintering and fabrication of a trilayer cell with composite NMC-LLZ to achieve desired performance metrics.

Reviewer 2:

The reviewer mentioned that the proposed future work is certainly appropriate for the continuation of the project. The reviewer said that the project team has several challenges ahead, however, it is well equipped for the challenge.

Reviewer 3:

The reviewer stated that the project team's major challenge is the thermochemical stability of the sintering process. The reviewer noted that it seems like the team has recognized the challenges but did not present details of the plan to address them.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that the research supports DOE objectives.

Reviewer 2:

The reviewer noted that designing new stable SSE-cathode and cathode-coatings-SSE is the goal for better performing SSB. The reviewer added that this project supports the overall DOE objectives, and that the use of computing techniques and power available at DOE facilities is also a plus.

Reviewer 3:

The reviewer mentioned that the objectives to develop novel processing techniques to fabricate NMC/LLZ composite cathodes with low interfacial resistance and enable high-performance ASSBs with an energy density of 450 Wh/kg and 1400 Wh/L and negligible degradation for 500 cycles, support overall DOE goals.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted that the project team has sufficient resources to conduct the work.

Reviewer 2:

The reviewer said that the resources and expertise seem sufficient to achieve the proposed milestones.

Reviewer 3:

The reviewer stated that the project, being both computational and experimental, requires manpower (theorists and experimentalists) as well as equipment and materials.

Presentation Number: bat484
Presentation Title: Developing an In-Situ Formed Dynamic Protection Layer to Mitigate Lithium Interface Shifting: Preventing Dendrite Formation on Metallic Lithium Surface to Facilitate Long Cycle Life of Lithium Solid State Batteries
Principal Investigator: Deyang Qu (The University of Wisconsin-Milwaukee)

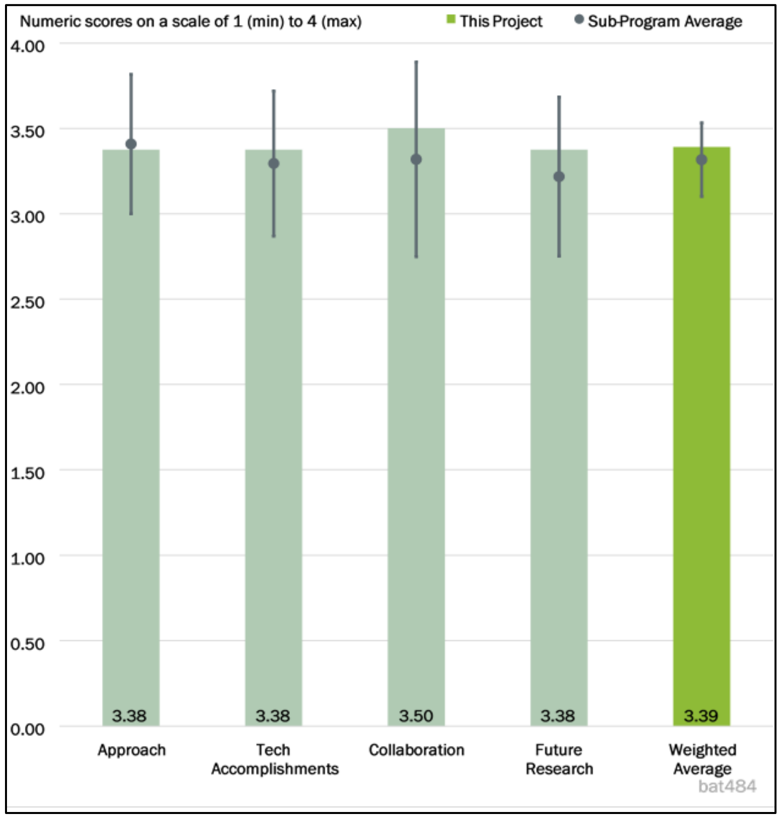


Figure 2-40 - Presentation Number: bat484 Presentation Title: Developing an In-Situ Formed Dynamic Protection Layer to Mitigate Lithium Interface Shifting: Preventing Dendrite Formation on Metallic Lithium Surface to Facilitate Long Cycle Life of Lithium Solid State Batteries Principal Investigator: Deyang Qu (The University of Wisconsin-Milwaukee)

Presenter

Deyang Qu, The University of Wisconsin-Milwaukee

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer remarked that the team addresses Li dendrite growth issue in solid state batteries by incorporating in situ formed dynamic protection layer on metallic Li. The reviewer declared that the approach includes synthesis, in situ monitoring, and cell performance test, which are well designed and feasible. The reviewer mentioned that the underlying physics shall be better understood in the later stage of the project.

Reviewer 2:

The reviewer stated that the project team has a very good approach for working to stabilize the very reactive Li interface and react with and destroy Li dendrites. The reviewer added that polymer coating that is formed in situ appears to inhibit Li dendrite growth, and doing that in situ means (in principle) that any reactive Li surface is coated with this polymer. The reviewer was somewhat surprised that the layer is not chewed up in the process of holding onto some of the Li.

The reviewer encouraged Professor Qu to start using much thinner solid-state electrolytes. The reviewer remarked that Professor Sakamoto showed the dramatically different mechanical properties of thin and thick Li and it is suspected that similar large differences will be seen in the behavior of thin versus thick SSEs.

Reviewer 3:

The reviewer said that the approach of this project, as performed by Qu and co-workers, aims to assess the performance of beyond Li-ion cells with Li metal anode by 1) gaining new knowledge about Li filament growth, 2) investigating new inter-layers for Li metal anodes, 3) developing a pouch cell with greater than 400 Wh/kg at C/3 for greater than 200 cycles, and 4) fabricating Li anodes with greater than 2Ah/g gravimetric energy density. The reviewer stated that the team's approach includes the development of an in situ and operando cell to observe Li dendrite growth, formation of dynamic protection layers on metallic Li anode surfaces, and assessment of full Li metal cells with NMC811/SSE/Li cells and dimethoxy benzoquinone (DMBQ)/SSE/Li cells. The reviewer noted that while the first year of this project aims to develop the benchmark tests for these materials, the approach needs to have more focus towards fabricating thinner solid-state electrolytes as well as addressing possible interdiffusion between the sulfide-based solid-state electrolytes and the oxide-based NMC cathodes.

Reviewer 4:

The reviewer noted that the in-situ diagnostic tools are very powerful in studying the dendrite problem of lithium metal, and that the project is well-designed. The reviewer stated that the fundamental mechanism for the dynamic protection layer can be more clearly identified in the presentation—for example, by explaining how the protection layer evolves during cycling.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated there was very good progress and excellent work. The reviewer questioned the value of using low capacity and low voltage cathodes to enable sulfide electrolytes. The reviewer mentioned that the 250mAh/g, 2V cathode used here is good for showing progress on the Li side, but it's unclear if this can be performance or cost-effective when compared to NMC cathodes that provide 220mAh/g and 3.7V—almost 60% higher energy density.

The reviewer remarked that it was not clear if this polymer passivation layer also results in a coulombic efficiency needed for long term cycling. The reviewer mentioned that the 100 cycles shown is too short to see any clear CE shortfall, and added that the scale on the CE plot is 0-100, so even 99% (which is much too low) looks good.

Reviewer 2:

The reviewer stated that the project "Developing an In-Situ Formed Dynamic Protection Layer to Mitigate Lithium Interface Shifting: Preventing Dendrite Formation on Metallic Lithium Surface to Facilitate Long Cycle Life of Lithium Solid State Batteries" reports a number of important technical accomplishments, including assembly/testing of the new operando electrochemical cells; and the formation of new protective layers on Li metal anodes (e.g., organic and inorganic). The reviewer said that the performance of the cells is approaching the project goals, yet the project team still needs a relatively high stack pressure to cycle the as-assembled cells. The reviewer suggested that in the coming years, special attention should be given to fabricating thinner solid-state electrolytes; cycling at higher current densities with thin Li metal anodes (10-20 microns in thickness); and understanding the effect of the stack pressure on the electrochemical performance. The reviewer noted that the combination of these three thrusts will help achieve batteries with higher total specific energies.

Reviewer 3:

The reviewer noted good progress in this reporting period, however, it seems that the cycle life of the protected Li is still very far from the overall objective, in particular the pouch cell.

Reviewer 4:

The reviewer stated that the team developed an in-situ formed dynamic protection layer to prevent or reduce the Li dendrite formation. The reviewer added that the project team has tried conductive polymer, red P, indium (In)-Li alloy and LPSCl to prevent direct contact of halide with Li. The reviewer noted that some materials may reduce the Li dendrite growth judging from in situ/ex situ optical imaging. The reviewer said that significant cycling stability improvement has been found with the protection. The reviewer remarked that in some slides such as Slide 12, it is unclear what protection layer the team refers to. The reviewer mentioned that cycling stability data from polymer and red P protection approaches seem to be needed in the follow-up studies.

The reviewer said that the halide/LPSCl dual electrolyte work seems to be less relevant to the in situ formed protection layer, and that it is not clear if additional protection layer was used on metallic Li and what was used.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted no issues, and remarked that there are good interactions with Millpore, national laboratories, and universities.

Reviewer 2:

The reviewer stated that the project team appears to have close, appropriate collaborations, especially with labs outside of the University of Wisconsin - Milwaukee. The reviewer said that specifically, the PI works with the University of Washington, Cornell University, PNNL, BNL, as well as Millipore Sigma. The reviewer notes that some work was completed in collaboration with Wuhan University in China (to develop the spectroscopy-based techniques). The reviewer said that the combination of these individuals will ensure a thorough understanding of the new interlayers as well as the performance of the solid-state batteries.

Reviewer 3:

The reviewer noted that there are multiple collaborations with universities and national laboratories.

Reviewer 4:

The reviewer reported that the contributions from collaborators have been clearly shown in Slide 15.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer noted good future research.

Reviewer 2:

The reviewer remarked that the proposed future research looks logical.

Reviewer 3:

The reviewer stated that for future work, the project team will optimize and down select the Li protection layer, fabricate pouch cell, and understand the fundamental mechanisms. The reviewer agreed that this is very logical planning, and if successful, it will be a big step in addressing the electrolyte-Li interfacial stability issues.

Reviewer 4:

The reviewer stated that the project "Developing an In-Situ Formed Dynamic Protection Layer to Mitigate Lithium Interface Shifting: Preventing Dendrite Formation on Metallic Lithium Surface to Facilitate Long Cycle Life of Lithium Solid State Batteries" will end on September 30, 2022, and is approximately 50% complete. The reviewer reported that the proposed future work includes further experiments to elucidate dendrite/filament growth in the as-assembled all-solid-state batteries; demonstration of the effectiveness of the organic protection layers towards Li plating and suppression of filaments; optimization of material processes as well as cell fabrication procedures; and fabrication of 1 Ah pouch cells for final deliverables. The reviewer noted that while this proposed work is ambitious, this work relies on the funding levels and coordination among the multiple researchers that contribute to this project. The reviewer urged the project team to down select the materials to focus on the best performing solid-state electrolyte/cathode combination, in order to mitigate the risk. The reviewer added that once identified, the team can focus on establishing degradation models to better guide optimization studies. The reviewer suggested that once the materials are down selected, the team dedicates efforts to form thin solid electrolyte films (e.g., 20-40 microns in thickness) of the chosen solid-state electrolyte.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that the work is very relevant, as stabilizing the Li interface is the number one problem in battery R&D and success would enable a new class of high energy inexpensive EV batteries.

Reviewer 2:

The reviewer stated that this project has a strong relevance to DOE. The reviewer remarked that specifically, the objective of this project is to overcome the performance barriers associated with all-solid-state batteries by specifically diagnosing electrochemical phenomena at solid-solid interfaces and by forming dynamic surface protection layers on Li metal anodes. The reviewer said that these results have obvious and direct implications to the electric vehicle market.

Reviewer 3:

The reviewer noted that protecting lithium anode is critical for developing solid-state batteries.

Reviewer 4:

The reviewer said yes, and added that solving the interfacial stability issue will enable the use of highly conductive and easy processing halide and sulfide electrolytes for high-energy-density high-safety all-solid-state batteries. The reviewer concluded that it thus will support the DOE objectives in clean energy storage and utilization.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted no issues.

Reviewer 2:

The reviewer stated that the project has sufficient resources.

Reviewer 3:

The reviewer said that the resources are adequate for the scope of the work.

Reviewer 4:

The reviewer stated that the project team was able to meet most of its proposed milestones even despite COVID-19. The reviewer added that the team has the proper equipment and resources to carry out this research, and that it was able to build new facilities and capabilities in order to enable this work. The reviewer remarked that this team has a number of active collaborations (University of Washington, Cornell University, PNNL, BNL, as well as Millipore Sigma), which can ensure the success of the project moving forward. The reviewer suggested that the team should focus on making thin solid electrolyte membranes in the near future, which may require additional equipment. The reviewer concluded that overall, this team appears to have sufficient resources to complete this work.

Presentation Number: bat485
Presentation Title: Molecular Ionic Composites: A New Class of Polymer Electrolytes to Enable All Solid-State and High Voltage Lithium Batteries
Principal Investigator: Louis Madsen (Virginia Polytechnic Institute and State University)

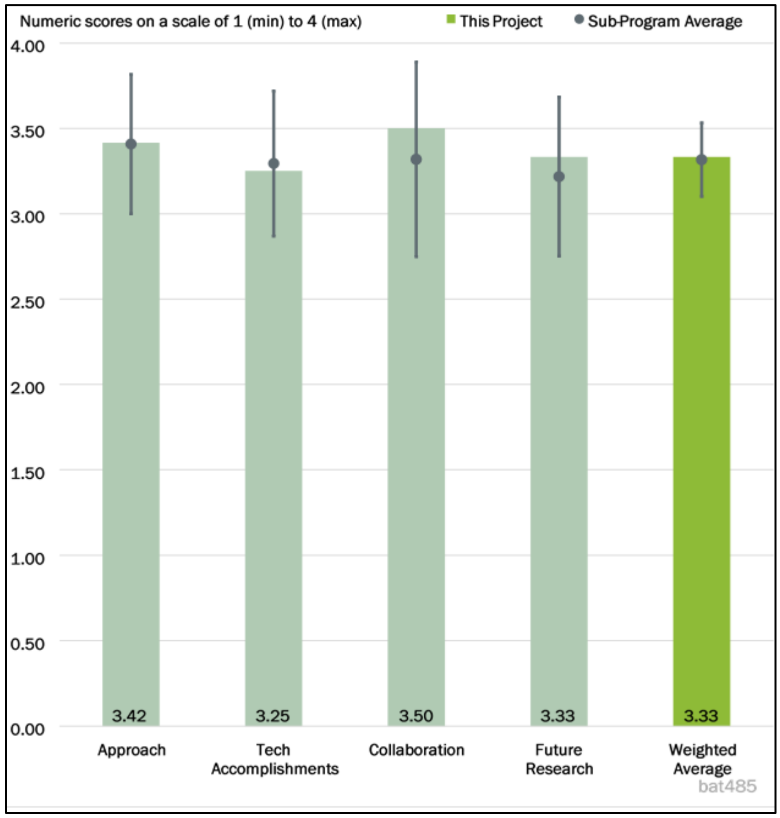


Figure 2-41 - Presentation Number: bat485 Presentation Title: Molecular Ionic Composites: A New Class of Polymer Electrolytes to Enable All Solid-State and High Voltage Lithium Batteries Principal Investigator: Louis Madsen (Virginia Polytechnic Institute and State University)

Presenter

Louis Madsen, Virginia Polytechnic Institute and State University

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that the PI uses molecular ionic composite as the solid electrolyte to meet the general requirements of high ionic conductivity, good mechanical strength, and high voltage stability. The reviewer said that the PIs shows clear understanding of state-of-the-art of solid-state batteries and the challenges to be addressed. The reviewer noted that the proposed molecular ionic composite is a new material that was not or little explored previously.

Reviewer 2:

The reviewer mentioned that the approach is sound and novel, and that the technical barriers have been addressed for the most part.

Reviewer 3:

The reviewer said that the project team is developing a new class of SE, which is a bull’s eye for an important barrier. The reviewer noted that the project exacerbates low temperature performance.

Reviewer 4:

The reviewer stated that in the “Approach” section, the project team indicates that it will develop the electrolyte, evaluate it electrochemically, and measure and understand the transport properties. The reviewer added that in reality the team was performing a lot of testing at elevated temperatures and at currents considered low for Li-ion (less than 1 mA/cm^2). The reviewer remarked that the team then tested it with $LiFePO_4$ as a cathode and just the polymer as the binder. The reviewer said that with NMC, the project team uses a combination of binder and, what looks like ionic liquid to make a cell but does not provide cycling data.

Reviewer 5:

The reviewer noted that the targeted elastic modulus of greater than 1 GPa seems too low to overcome lithium dendrite penetration.

Reviewer 6:

The reviewer remarked that the team aims to develop better polymer electrolytes based on molecular ionic composites. The reviewer noted that combining highly rigid and charged polymers such as Li-PBDT with lithium salt and additive can help improve the performance while maintaining good mechanical strength of the polymer electrolyte. The reviewer stated that the key challenges would be the low Li transference number and the limited oxidative stability of the proposed polymer electrolytes.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that the development of a new polymeric electrolyte is a significant accomplishment in itself. The reviewer added that the challenge seems to be to deal with a somewhat low transference number, at least compared to ceramic single ion conductors. The reviewer noted that there is a great benefit relative to ceramics in processability. The reviewer remarked that it is somewhat surprising that the interface should cause poor low temperature performance, as it would be expected to be less of problem for a polymer system.

Reviewer 2:

The reviewer stated that using molecular ionic composite (MIC) as a binder for the positive electrode seems quite speculative since the mechanical properties of the MIC, including the adhesive strength, are either unknown or lower than PVDF. The reviewer added that the active material NMC to binder/carbon black (CB) ratio, NMC 811:CB:MIC= 8:1:1, is too low compared to the state-of-the-art.

Reviewer 3:

The reviewer mentioned that high ionic conductivity of 10^{-3}/cm has been achieved at room temperature. The reviewer noted that this number is very high for polymer electrolytes. The reviewer remarked that the Li transference number is only 0.12 which is lower than the mainstream liquid electrolytes. The reviewer stated that the project team also demonstrated excellent cycling data for the Li-Li symmetrical cell at various temperatures. The reviewer added that the interfacial resistance between polymer and Li seems to be high compared with that of other polymer electrolytes. The reviewer said that the current full cell (Li/LFP) data shows that the electrolyte would need to be cycled at elevated temperatures greater than 60^{o}C. The reviewer concluded that including the comparison of this data with polyethylene oxide (PEO)-based polymer cells will be helpful to evaluate the progress of this project.

Reviewer 4:

The reviewer stated that the cell runs great at 150^{o}C, and that the project team is looking into potential applications at such temperatures. The reviewer added that if the team can find such applications, it would benefit by being able to develop the technology.

The reviewer mentioned that it can be made using low-cost, scalable processes, which is a major plus. The reviewer said that the fact that it needs moderate to high temperatures is a significant downside, however, and limits its applicability. The reviewer remarked that considering that the material is made up largely from ionic liquids, there is doubt that the team can lower the temperature.

Reviewer 5:

The reviewer stated that the PI has been very productive in terms of publications, including several high impact papers. The reviewer added that the synthesized molecular ionic polymer electrolyte shows high ionic conductivity (up to 1.5mS/cm) at room temperature.

The reviewer noted that the transference number is still low at this point (0.12) and needs solid improvement. The reviewer reported that it seems that $LiFePO_4$ is the only cathode used for all the tested cells, and that the NMC is mentioned in the slide, but no electrochemical performance is shown.

Reviewer 6:

The reviewer stated that the synthesized composited electrolytes consist of ionic liquids and a polymer to form self-standing, transparent films. The reviewer noted that the project team measured the conductivity as a function of temperature and the diffusion coefficient. The reviewer did not know what is meant by the diffusion coefficient of the anion and the cation. The reviewer added that the team measured its mechanical properties, and measured the cycleability in a Li symmetric cell at different temperatures and different current densities. The reviewer noted that the highest current density at room temperature was 0.15 mA/cm^2 with an overvoltage of 200 mV, which is a resistance of 1333 ohm.cm^2 (not great). The reviewer said that the team achieved 800 cycles while passing 0.05 mAh/cm^2 per cycle (not that impressive). The reviewer declared that the team made a cell with $LiFePO_4$ as cathode and achieved 350 cycles before irregularities appeared in the coulombic efficiency, and that there was no mention of the area specific capacity of the cell. The reviewer mentioned that the team made a cell with NCM as the cathode and did not provide any cycling data.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer stated that the collaboration is good across the team.

Reviewer 2:

The reviewer mentioned that the project team used SLAC and universities to characterize material and synthesize material.

Reviewer 3:

The reviewer stated that the collaboration between the PI and co-PI appears to be highly effective and productive.

Reviewer 4:

The reviewer said that the project team has a strong collaboration with Pennsylvania State University (PSU), University of North Carolina (UNC), and Stanford Synchrotron Radiation Lightsource (SSRL).

Reviewer 5:

The reviewer remarked that the PI collaborated with both national laboratories and universities.

Reviewer 6:

The reviewer noted moderate collaboration aimed at supporting the main work at Virginia Tech.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer stated that appropriate work is outlined to further develop this project.

Reviewer 2:

The reviewer mentioned that appropriate goals for future work have been laid out.

Reviewer 3:

The reviewer said that the PI is aware of aspects that need to be improved such as decreasing electrolyte thickness, increasing transference number, and increasing the cathode voltage (from $LiFePO_4$ to NMC). The reviewer noted that the PI proposed specific measures to address them in future research.

Reviewer 4:

The reviewer said that the project team is now going to start optimizing its chemistry for NCM cells. The reviewer added that the team is planning to do what most solid-state systems need to do, which is to address stability at the cathode, develop a technique for making a thinner separator of the electrolyte, and improve the ionic conductivity, all with no clear plan to do any of them.

Reviewer 5:

The reviewer stated that the mechanical property measurements can be further enhanced, including the measurement of interfacial properties between MIC and the active materials, and that between the electrode and the current conductors.

Reviewer 6:

The reviewer noted that more research should be done to understand the reason for the limited Li transference number. The reviewer said that the project team will also need to study in detail the interfaces between Li anode and polymer electrolyte, as the current interfacial resistance is large for an electrolyte with a 10-3 S/cm ionic conductivity. The reviewer also recommended comparing the data with PEO-based cells using the same electrodes. The reviewer was unclear on how the team will improve the oxidative stability of the polymer electrolytes to enable 4V or even 5V cathodes, even though the co-PI slightly mentioned some promising results.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer stated that the processability and potential low cost directly support the DOE objectives.

Reviewer 2:

The reviewer noted that the DOE sees value in investigating Li based cells, and that this project team is working in that direction.

Reviewer 3:

The reviewer remarked that the project is highly relevant to the overall DOE objectives.

Reviewer 4:

The reviewer confirmed that the efforts will enable high voltage polymer based solid-state batteries.

Reviewer 5:

The reviewer said yes, the project team is aiming at an important goal, finding a new class of SEs.

Reviewer 6:

The reviewer remarked that this project supports the overall DOE objectives in providing clean energy solutions. The reviewer added that specifically, the beyond Li-ion battery option has higher energy density and better safety characteristics than the conventional liquid electrolyte-based Li-ion batteries.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer mentioned that the project is resourced appropriately.

Reviewer 2:

The reviewer noted that the project team has excellent resources both internally at Virginia Tech and through the collaborators.

Reviewer 3:

The reviewer mentioned that the resources are sufficient.

Reviewer 4:

The reviewer observed sufficient resources.

Reviewer 5:

The reviewer noted that the resources for the project are sufficient to achieve the stated milestones in a timely fashion.

Reviewer 6:

The reviewer stated that this is in line with the other projects, and that it is risky research funded at an 80% level by DOE. The reviewer remarked that one needs to balance promise with reality.

Presentation Number: bat486
Presentation Title: All Solid State Batteries Enabled by Multifunctional Electrolyte Materials
Principal Investigator: Pu Zhang (Solid Power, Inc)

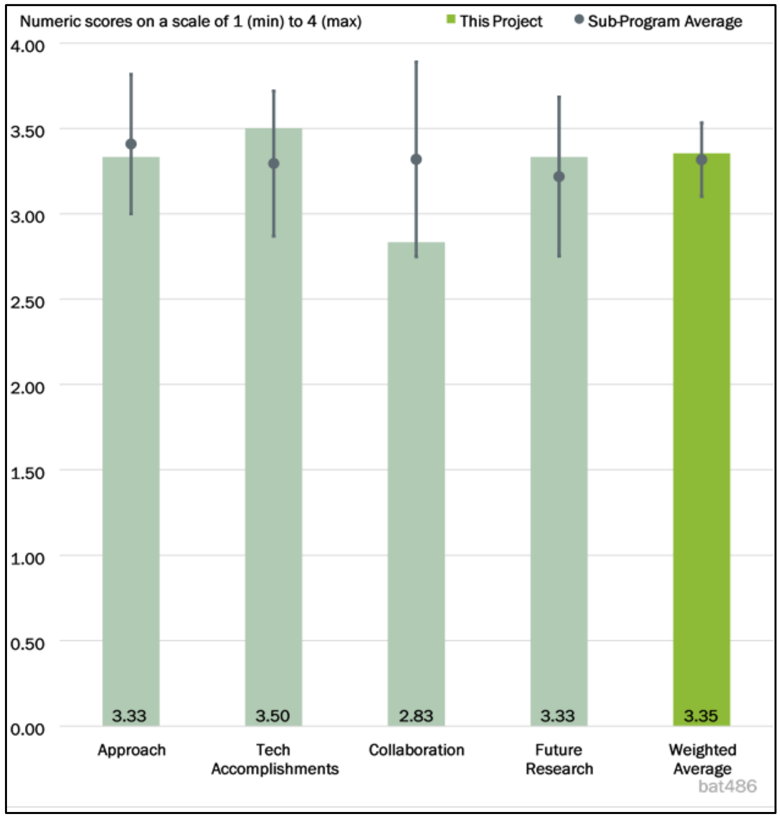


Figure 2-42 - Presentation Number: bat486 Presentation Title: All Solid State Batteries Enabled by Multifunctional Electrolyte Materials Principal Investigator: Pu Zhang (Solid Power, Inc)

Presenter

Pu Zhang, Solid Power, Inc

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that the approach of this project, as performed by Zhang and co-workers, aims to develop solid-state electrolytes to enable high energy density solid-state batteries by using roll-to-roll-processes. The reviewer added that the general approach encompasses the formation of slurry-based deposition of cathode composites followed Solid Power's proprietary solid electrolyte. The reviewer mentioned that this approach is both economical as well as effective, as it requires the same (general) equipment that Li-ion battery manufacturing requires, so transfer from Solid Power to other production lines is expected to be relatively quick. The reviewer said that in terms of the performance, this approach yields cells that retail 93% of their capacity after 200 cycles. The reviewer concluded that overall, the approach of Zhang and co-workers addresses the technical barriers, and their team is on track to meet their goal in the coming fiscal year.

Reviewer 2:

The reviewer remarked that the project team develops highly conductive sulfide-based electrolyte for the assembly of solid-state pouch cells using R2R methods. The reviewer said that it will address the scaling up barriers for solid-state batteries for commercial applications.

Reviewer 3:

The reviewer stated that it is very difficult to assess the approach, given the lack of detailed technical data. The reviewer mentioned that the main issue with sulfide electrolytes is their instability at voltages above 3.5V, but that it is not clear how Solid Power is addressing this. The reviewer noted that the speaker said it is doing so with surface coatings and SSE dopants, but that is too vague to assess.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer stated that the project "All Solid-State Batteries Enabled by Multifunctional Electrolyte Materials" reports a number of important technical accomplishments, including 1) roll-to-roll processing of solid-state electrolytes as films, and 2) the formation of solid electrolyte-cathode interfaces that ensure charge-transfer at C/5 and C/2 rates. The reviewer noted that as of now, the team is on track to meet FY 2021 goals and is on track to meet FY 2022 goals. The reviewer reported that though the performance of the solid electrolyte/cathode interface retains greater than 93% of the capacity after 200 cycles, the degradation pathway of the cathode/solid electrolyte interface is not entirely clear.

Reviewer 2:

The reviewer said that the project team has accomplished the set milestones and made great progress. The reviewer added that ionic conductivity of 4.5 x 10-3 S/cm at room temperature (RT), CCD greater than 6 mA/cm^2, and 93% capacity retention after 220 cycles were achieved, which leads to one step further towards commercial application.

Reviewer 3:

The reviewer said that the results to date look reasonable but to assess the high V stability of this sulfide SSE, the PI should conduct some longer-term calendar life studies at 100% SOC and monitor the capacity and impedance of the cell. The reviewer added that it is very nice that Solid Power has gotten its SSE to 70 microns, which is at least in the range of where commercial SSEs will need to be.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer noted that SP has the University of California San Diego (UCSD) on its research team, but that it was not very clear what contribution UCSD made in these results, as there was no discussion of "material characterization or cell failure analysis."

Reviewer 2:

The reviewer remarked that this team appears to have close, appropriate collaborations between team members as well as its sub-contractors at UC San Diego. The reviewer added that specifically, the synthesis, profess development, cell assembly, and cell testing is completed in house at Solid Power, while the material characterization and cell failure analysis is completed at UC San Diego. The reviewer said that both teams appear to work synergistically on this project.

Reviewer 3:

The reviewer indicated that the collaboration seems to be on schedule.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer remarked that it is good that Solid Power is moving toward even thinner SSEs and is planning to build and test 300 and 350Wh/kg cells. The reviewer noted that silicon cells are currently achieving 300-

350Wh/kg and over 1000 cycles. The reviewer encouraged SP to add calendar life studies here to demonstrate the stability of their system at 4xV.

Reviewer 2:

The reviewer noted that the project "All Solid-State Batteries Enabled by Multifunctional Electrolyte Materials" is anticipated to end in September 2022 and is approximately 60% complete. The reviewer said that proposed future work includes (1) demonstrations of solid-state cells with 500 cycles in a 300 Wh/kg design by Q8 and (2) fabrications of prototype pouch cell greater than or equal to 2 Ah with 1000 cycles, 350 Wh/kg by Q12. The reviewer mentioned that this future work will encompass the fabrication of thinner solid electrolytes in order to improve the specific capacity of the battery. The reviewer stated that in terms of future work, more time will need to be dedicated to the fabrication of thinner solid electrolyte separators (e.g., 20-40 microns in thickness) through the exploration of new slurry formulations. The reviewer added that the Solid Power team plans to explore the cell operation at room and decreased temperatures. The reviewer reported that such studies are important to enable batteries that will perform well over a wide range of temperatures. The reviewer remarked that in order to deliver pouch cells with greater than 350 Wh/kg, Solid Power is exploring NMC-based cathodes with greater than 80% Ni content (validation pending). The reviewer declared that if these cathodes perform as intended, Solid Power is on track to meet their targets this upcoming fiscal year. The reviewer concluded that collectively, the proposed future research is appropriate considering the barriers noted.

Reviewer 3:

The reviewer stated that the project team proposes to further improve the performance and the cell level capacity. The reviewer mentioned that it is not clear how the team addresses the electrode-stability issues for the sulfide system, which many research groups are struggling with.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer mentioned that Li metal SSB are clearly relevant to future EV plans.

Reviewer 2:

The reviewer reported that this project has a strong relevance to DOE, specifically when it comes to the objective of this project which is to overcome processing and performance barriers associated with all-solid-state batteries. The reviewer noted that the Solid Power team is addressing these batteries by developing roll-to-roll processes of sulfide-based electrolytes that can be directly cast to form dense cathode/solid electrolyte layers that can, in turn, be integrated in next-generation batteries. The reviewer concluded that these results have obvious and direct implications to the electric vehicle market.

Reviewer 3:

The reviewer said that solid state batteries developed by the project team are probably the closest ones for large scale commercialization.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer stated that the project team was able to meet most of its proposed milestones in FY 2021. The reviewer noted that the team has the proper equipment and resources to carry out this research, and that the team was able to sub-contract some of the materials characterization as well as the failure analysis. The reviewer concluded that overall, the team appears to have sufficient resources to complete the proposed work in a timely fashion.

Reviewer 2:

The reviewer remarked that the budget is adequate for the proposed experimental work including cell development and failure mechanism studies.

Reviewer 3:

The reviewer had no comments.

Presentation Number: bat487
Presentation Title: Developing Materials for High-Energy-Density Solid State Lithium-Sulfur Batteries
Principal Investigator: Donghai Wang (Penn State University Park)

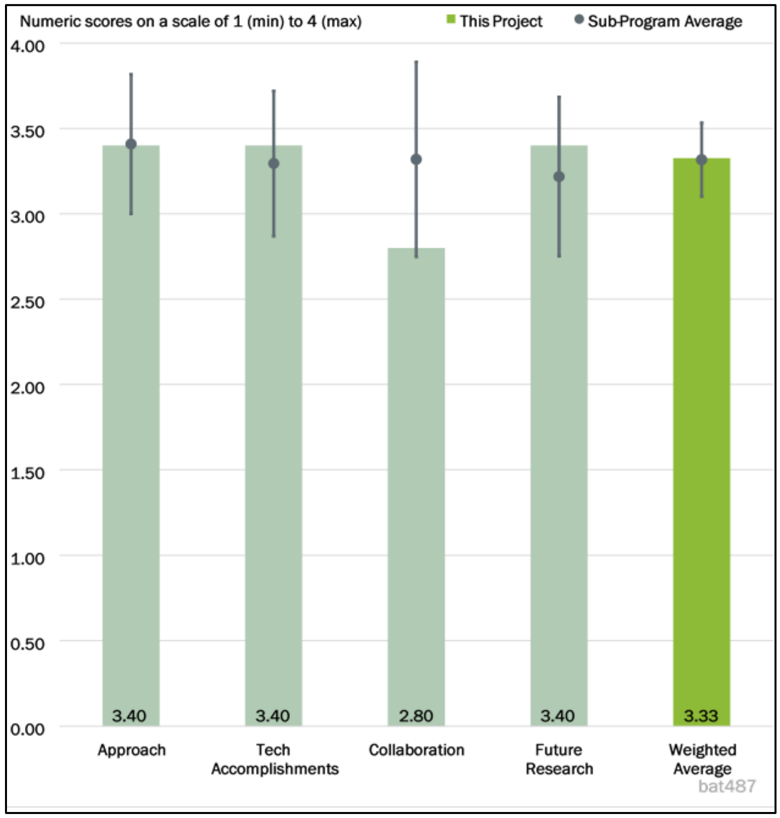


Figure 2-43 - Presentation Number: bat487 Presentation Title: Developing Materials for High-Energy-Density Solid State Lithium-Sulfur Batteries Principal Investigator: Donghai Wang (Penn State University Park)

Presenter

Donghai Wang, Penn State University Park

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer stated that this project is very well designed and that all proposed, ambitious goals are feasible.

Reviewer 2:

The reviewer stated that overall, it looks like the project team is working hard on solid state Li/S and solid electrolyte development. The reviewer added that full-cell testing with Li-In is a question for the project team’s approach. The reviewer pointed out that the team obviously is not able to cycle against Li metal yet, but that should remain front and center as the target. The reviewer noted that it is good to see that the team is going for high weight fraction of sulfur in cathodes, and also reasonable electrode loadings.

Reviewer 3:

The reviewer remarked that the project team worked on both high ion conductivity solid electrolytes and high sulfur content cathodes. The reviewer mentioned that these approaches are quite effective in achieving the team’s objective to make high energy density solid-state Li-S batteries.

Reviewer 4:

The reviewer said that the PIs clearly address the key technical barriers such as Li ion conductivity and stability of solid-state electrolyte against Li metal of Li-S all solid state batteries. The reviewer remarked that the approaches such as novel solid state electrolyte design, synthesis and composition optimization of glass ceramic solid state electrolyte and argyrodite thiophosphate with targeted Li ion conductivity greater than 3 mS/cm, and development of high S loaded Li-S solid state batteries, are novel and innovative. The reviewer added that the in-situ pressure monitoring of the cell in real time to understand fundamental mechano-electrochemical property during charge/discharge process will open the new fundamental science on performance degradation mechanism of the solid-state Li-S battery system. The reviewer noted that the experimental work is well designed and feasible to address the major issues of all solid-state batteries.

Reviewer 5:

The reviewer declared that building on previous experience on glass-ceramic solid electrolytes, the project team optimized the composition (amount of Al_2S_3) in the SSE1 for maximum performance. The reviewer added that new formulations were presented (SSE2 and SSE3) that show improved performance. The reviewer assumed that the new formulations are based on SSE1, and noted incremental progress toward the goal.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that the work on solid electrolytes appears to be going well. The reviewer explained that the use of a Li-In alloy helps with the results, but that it is not envisioned in the milestones. The reviewer added that it looks like the project team still needs to reach its June 2021 milestone in terms of greater than 1000 mAh/g for the sulfur cathode.

Reviewer 2:

The reviewer expressed that the project team's accomplishments are quite impressive—achieved greater than 1000 mAh/g capacity with the developed sulfur cathode (at 0.3^{o}C and 60^{o}C), and several solid electrolytes with ionic conductivity approximately 4 mS/cm at 25^{o}C.

Reviewer 3:

The reviewer noted that excellent progress has been made both on technological and fundamental scientific point of view. The reviewer said that excellent cyclability of all solid-state Li-S batteries at 60^{o}C is an excellent achievement of the PIs. However, the PIs need to demonstrate the feasibility to achieve energy density of ^{3}500Wh/kg of Li-S cell using the Li-In metal host anode and high S loaded cathode at room temperature and below.

Reviewer 4:

The reviewer stated that the project progress is on schedule, with good conductivities achieved, and performance at room temperature and 60^{o}C remaining in progress.

The reviewer posed a few questions about the presentation. Regarding Slide 6, why is there an optimum amount of Al_2S_3 in the solid electrolyte? What happened for compositions x greater than 12? Which Li is mobile or more mobile in the following formulation—"Glass-ceramic solid electrolytes aLi_2S-bP_2S_5-cLi_3N-xAl_2S_3"?

Referencing Slide 14, the reviewer asked the project team to elaborate on better performance (capacity) with initial cycling. Concerning Slide 15, the reviewer inquired as to whether the crack in the cathode that is extended and parallel to the interface could be due to outside pressure.

Reviewer 5:

The reviewer stated that two new thiophosphate solid electrolytes were successfully synthesized using solid-phase and liquid- phase synthesis, demonstrating impressive ionic conductivity greater than 4 mS cm^{-1} at 25^{o}C. the reviewer added that the project team developed new carbon materials and solid-state electrolytes for high-energy sulfur cathode with high sulfur utilization (approximately 1400 mAh g^{-1} at 0.1^{o}C) and stable cycling for 1000 cycles at 2^{o}C (800-950 mAh g^{-1}). The reviewer remarked that the project is in great shape in terms of milestones, but that publications are not reported.

The reviewer reported that the chemical environment of aLi_2S-bP_2S_5-cLi_3N-$12Al_2S_3$ (SSE-1) was studied by x-ray photoelectron spectroscopy (XPS). The reviewer added that chemical and electrochemical stability against lithium metal anode should be further evaluated with XPS and improved, if necessary. The reviewer stated that the electrochemical stability against lithium metal anode at higher current densities should be studied since polarization resistance is already increasing at 0.75 mA cm^{-2}. The reviewer said that the cycling stability issue of sulfur cathode at high areal sulfur loading (greater than or equal to 5 mg sulfur cm^{-2}) needs to be resolved, and that room temperature performance needs to be achieved.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer declared that the PI has good collaborations with University of Illinois at Chicago colleagues for theory and modeling work.

Reviewer 2:

The reviewer stated that the project is mainly at PSU, but there is a partner at the University of Illinois at Chicago (UIC).

Reviewer 3:

The reviewer said that the project is conducted by the Pennsylvania State University team, with their UIC partners, and that no other collaboration is shown in the report. The reviewer encouraged the project team to expand its collaborations with national laboratories and industry.

Reviewer 4:

The reviewer noted that the results presented so far are from the lead institution only.

Reviewer 5:

The reviewer remarked that little collaboration from theory group at UIC is apparent.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer stated that the proposed future work is effectively planned with clear and important goals.

Reviewer 2:

The reviewer noted that the project team should also consider adding future work on use of Li metal rather than Li-In.

Reviewer 3:

The reviewer stated that the project team realized the remaining challenges and has identified concrete steps in future research. The reviewer reported that the major challenge is to lower the operating temperature of the Li-S battery from 60^{o}C to RT, while keeping the high capacity. The reviewer added that since the objective of the project is to develop the high energy density Li-S ASSBs, the team should report the energy density in addition to the charge capacities of the batteries, especially since Li-In is being used as anode.

Reviewer 4:

The reviewer stated that the future work target to improve electronic conductivity of the SSE greater than 5 mS/cm, as well as the development of high S loading electrode and using dendrite free Li as an anode, is well planned to address the key barriers of all solid-state Li-S based battery.

Reviewer 5:

The reviewer remarked that the proposed future work should address the remaining challenges and milestones, and that more characterizations are needed to show dendrite mitigation.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that it is addressing the battery barriers.

Reviewer 2:

The reviewer noted that Li-S ASSBs are one of the major routes to realize all-electric vehicles by 2030.

Reviewer 3:

The reviewer said that the development of novel solid-state electrolyte of high ionic conductivity along with identification of high S loaded electrode configurations (³6mg/cm^2) for use in all solid-state Li-S batteries at room temperature, can meet the DOE targeted energy density greater than or equal to350 Wh/kg and cycle life approximately 1000 cycles for the next-generation EV applications.

Reviewer 4:

The reviewer mentioned that the development of new stable solid-state electrolytes that can mitigate Li dendrite growth while maintaining good performance, certainly supports the overall DOE objectives.

Reviewer 5:

The reviewer confirmed that this project's goals are in line with DOE goals to develop novel solid-state electrolytes with high ionic conductivity and good stability against lithium metal, and demonstrate safe, low-cost, high performance Li-S ASSBs with high energy density, high sulfur content and long cycle life (greater than 1000 cycles).

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer stated that resources appear adequate.

Reviewer 2:

The reviewer said that the current resources are sufficient to achieve the project targets.

Reviewer 3:

The reviewer declared that the amount of work needed to accomplish the tasks is consistent with the current funding.

Reviewer 4:

The reviewer noted that the resources and expertise seem sufficient to achieve proposed milestones.

Reviewer 5:

The reviewer mentioned that the project team has efficient resources to conduct the project, but that it is still encouraged to develop more collaborations with other institutions.

Presentation Number: bat488
Presentation Title: Fundamental Understanding of Interfacial Phenomena in Solid State Batteries
Principal Investigator: Xingcheng Xiao (General Motors, LLC)

Presenter

Xingcheng Xiao, General Motors, LLC

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

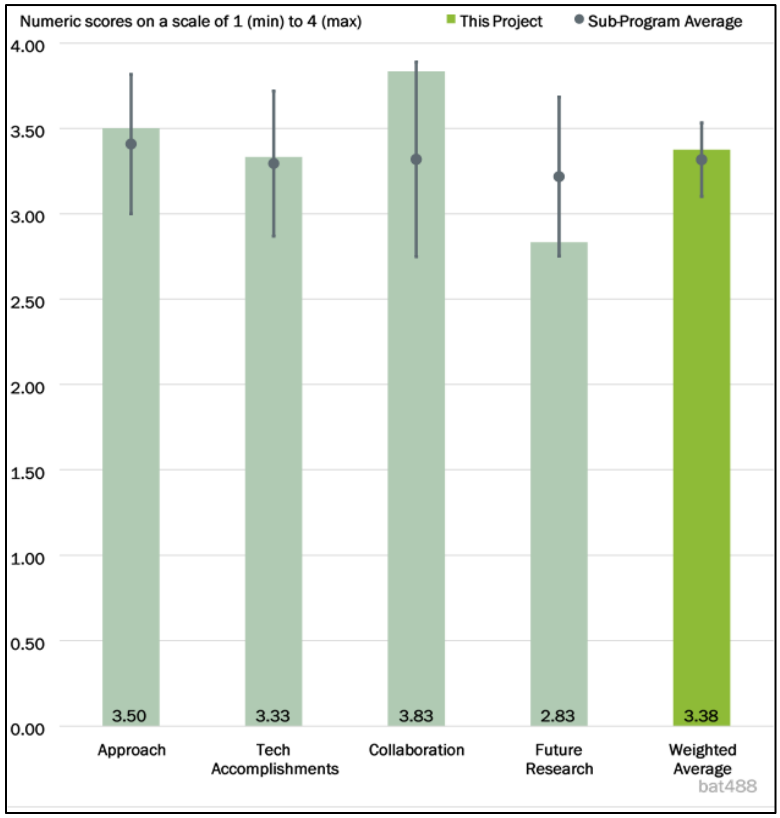


Figure 2-44 - Presentation Number: bat488 Presentation Title: Fundamental Understanding of Interfacial Phenomena in Solid State Batteries Principal Investigator: Xingcheng Xiao (General Motors, LLC)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer stated that the approach of this project, as performed by Xiao and co-workers, aims to develop a fundamental understanding of dynamic phenomena in solid-state batteries. The general approach encompasses multilayer model systems; in situ characterization of critical chemo-mechanical and transport properties; postmortem analysis; and interface engineering to form improved interfaces in next-generation batteries. The reviewer remarked that the combination of these approaches is expected to elucidate charge-transfer at interfaces and yield important strategies to improve the long-term cyclability in next-generation all-solid-state batteries. The reviewer concluded that overall, the approach of Xiao and co-workers addresses the outlined technical barriers, and that the team is on track to meet its goal in the coming fiscal year.

Reviewer 2:

The reviewer stated that the project team uses the Li|LLZO|Li symmetric cell as the model system, develops in situ mechanical monitoring techniques to reveal the dynamic change of interface contact, and then evaluates nanocomposite interfacial layer to enhance both mechanical and chemical stability. The reviewer added that the team also investigates void/vacancy formation using simulation methods. The reviewer noted that the approach is appropriate to address the interfacial issues in solid state batteries.

Reviewer 3:

The reviewer voiced his support of investigating stabilizing surfaces on Li metal interfaces, but said that the use of a very thick LLZO that is of poor quality poses the question on the value of the improvements seen here. The reviewer mentioned that the improvement being provided by the coating might indeed be smoothing out the current density inhomogeneities introduced by the very large defects in these LLZO samples, but questioned how it is relevant when applied to a cell using a thin and nearly defect-free LLZO? The reviewer was concerned the project team might be fixing an irrelevant issue.

The reviewer added that even the more fundamental aspects of this project, like investigating interface phenomena and the stress evolution on early cycling, could be very strongly impacted by the thickness and quality (or lack thereof) of the LLZO and Li. The reviewer hoped that the techniques developed will translate to systems with thin Li and LLZO.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer mentioned that a very large number of results was presented, and that the volume of work was impressive. The reviewer remarked that it was nice to see more work on understanding the impact of pressure on cycling of Li metal anodes. The reviewer reported that the stabilizing interlayer developed and shown on Slide 17 is a good improvement over the team's baseline performance.

Reviewer 2:

The reviewer stated that the project "Fundamental Understanding of Interfacial Phenomena in Solid State Batteries" reports a number of important technical accomplishments:

- Developed reliable model systems and in situ techniques to investigate interface dynamic phenomena.
- Developed a model system to investigate the stress evolution in solid electrolyte at initial stage.
- Developed and integrated in situ nano-indentor to investigate mechanical behaviors of Li garnets.
- Investigated vacancy formation along the interfaces between Li and different compounds.
- Developed a nanocomposite interlayer for Li metal/solid electrolyte interfaces.

The reviewer added that overall, the large number of accomplishments from FY 2021 clearly demonstrates the capability of the project team and the coordinated approach to improve interfacial charge-transfer in solid-state batteries. The reviewer declared that as of now, the team is on track to meet FY 2021 goals. The reviewer agreed that there are some technical challenges facing this work in FY 2022, namely, it is difficult to characterize the interfacial fracture strength between Li metal and solid-state electrolytes. The reviewer added that further correlation between experiment and theory will need development in the coming fiscal year.

Reviewer 3:

The reviewer mentioned that the project team has made very nice progress. The reviewer said that the team discovered Li plating induced compressive stress accumulation likely arising from the metallic Li nucleation in the LLZTO near the Li plating side. The reviewer remarked thar it seems to be dependent of current density, but that more well-designed experiments are needed to determine the correlation. The reviewer noted that the simulation on vacancy formation tendency with various materials is intriguing, and that it would be great if those findings can be compared with experimental observations. The reviewer stated that the critical current density of the nanocomposite coated LLZO is still very small, only 6.4 uA. The reviewer asked if the team can comment on how to further improve the CCD to a more practical value.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer remarked that there was good collaboration.

Reviewer 2:

The reviewer noted that the project team has demonstrated close, appropriate interactions between team members as well as their collaborators at Brown University, University of Kentucky, Massachusetts Institute of Technology (MIT), and PNNL. The reviewer added that these efforts are exemplified by the large number of accomplishments shown from FY 2021.

Reviewer 3:

The reviewer stated that the collaboration across the team is great, based on the publications produced together.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer stated that future work is reasonable. The reviewer encouraged the project team to redouble its efforts to do this work on commercial relevant materials, meaning thin (30-50 micron) Li and reasonable quality and thickness (30-50 micron) LLZO. The reviewer added that, if not already planned, it might be interesting to theoretically investigate LLZO surface dopants that would enable strong chemical bonding to Li metal and/or cathode/binder particles. The reviewer said that, as is well known, interfacial impedance is generally a major challenge in solid state cells.

Reviewer 2:

The reviewer remarked that the project "Fundamental Understanding of Interfacial Phenomena in Solid State Batteries" is anticipated to end in December 2022 and is approximately 45% complete. The reviewer stated that the proposed future work includes investigating different crystal orientations and comparing various properties in Li garnets; understanding the mechanisms responsible for the observed changes in mechanical properties of solid electrolyte and developing effective mitigation strategies to maintain mechanical integrity; and optimizing experimental techniques to better enable fundamental measurements. The reviewer declared that the combination of this future research is expected to better overcome the noted technology barriers. The reviewer added that while the technical challenges are apparent, it is not entirely clear how these challenges will be overcome in future experiments (e.g., what specific experiments/milestones and go/no-go points will be used in the coming fiscal year).

Reviewer 3:

The reviewer mentioned that the team did not show future work in the slides, although it did present the remaining challenges and barriers.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer remarked that as with other SSB research projects, this work is highly relevant.

Reviewer 2:

The reviewer stated that this project has strong relevance to the DOE, specifically in that the objective of this project is to develop an understanding underpinning the degradation modes at electrode solid electrolyte interfaces, particularly mechanical and chemical degradation. The reviewer added that such degradation at interfaces compromises the cyclability of next generation batteries. The reviewer remarked that here, the team, led by GM, investigates dynamic evolutions of the mechanical/transport properties and structure/composition of the interfaces in solid-state batteries. The reviewer concluded that these results have obvious and direct implications to the electric vehicle market.

Reviewer 3:

The reviewer mentioned that mechanical stability is a critical issue for all solid-state Li batteries, and that it is important to pin down the stress evaluation during battery testing, the effect of packing pressure on cell performance, and to investigate methods to alleviate the problem of improving the cycling stability of ASSLBs.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer mentioned no issues with resources.

Reviewer 2:

The reviewer stated that the project team was able to meet its proposed milestones in FY 2021. The reviewer commented that the team has the proper equipment and resources to carry out this research, and that GM was able to establish stronger collaborations with Brown University as well as with the University of Kentucky. The reviewer added that this team also worked with PNNL and MIT on in situ transmission electron microscopy (TEM) investigations as well as the synthesis of Li garnet-based structures. The reviewer concluded that overall, the team appears to have sufficient resources to complete the proposed work in a timely fashion.

Reviewer 3:

The reviewer indicated that the funds are appropriate compared to the scope of the work, and that the project team has a variety of experimental tools for synthesis and characterization. The reviewer noted that as the team mentioned, finite element simulation might be needed to quantify the stress evolution.

Presentation Number: bat489
Presentation Title: Multidimensional Diagnostics of the Interface Evolutions in Solid-State Lithium Batteries
Principal Investigator: Yan Yao (University of Houston)

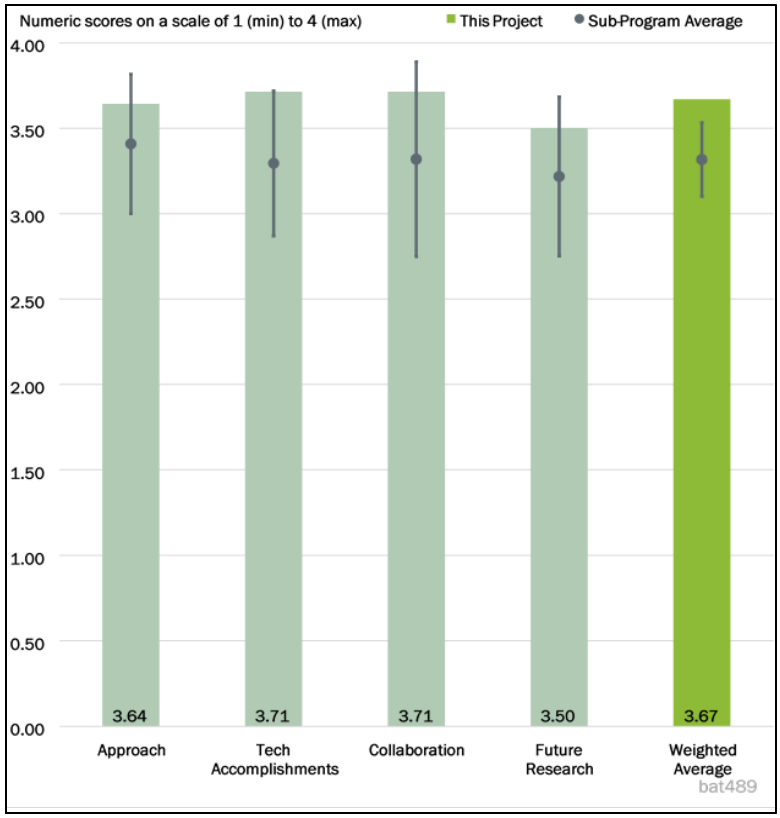


Figure 2-45 - Presentation Number: bat489 Presentation Title: Multidimensional Diagnostics of the Interface Evolutions in Solid-State Lithium Batteries Principal Investigator: Yan Yao (University of Houston)

Presenter

Yan Yao, University of Houston

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer noted that the work is very impressive in developing methods for studying solid state batteries, and that a very useful tool set has been thus far developed.

Reviewer 2:

The reviewer stated that the solid electrolytes being developed are air sensitive and known to react at the cathode and the anode. The reviewer remarked that the plan is to develop a transfer device that allows one to perform a number of diagnostics to a sample without ever exposing it to air.

Reviewer 3:

The reviewer declared that the air-free vessel appears to be too bulky to fit into, e.g., an ion mill to make cross section samples of tens of micrometer in dimension for SEM, XRD, and electrochemical characterization.

Reviewer 4:

The reviewer commented that developing air-free vessel and cell designs are critical to understanding many fundamentals (structural, chemical and mechanical) of solid-state batteries, given that many components of the cell such as electrolytes, Li anode, interphases are highly sensitive to air.

Reviewer 5:

The reviewer was impressed with the overall comprehensive effort to use a suite of diagnostic techniques on micro- and nano-cells. The reviewer acknowledged that the promise is that the team will be able to take advantage of all these techniques in a coherent way to improve its cells, as opposed to having a lot of diagnostic data standing on its own.

Reviewer 6:

The reviewer indicated that the PI proposes to design an air-free vessel with an in-situ cell test platform for in situ multimodal characterization of the solid-state battery cell. The reviewer added that such an approach addresses the challenges of high air sensitivity and multi-dimensional properties of the solid-state electrolyte, providing an effective method for understanding the interphase which is critical to solid state battery performance but very challenging to characterize accurately.

Reviewer 7:

The reviewer noted that this project focuses on the development of a diagnostic capability for solid-state-lithium-batteries. The reviewer added that the tool set developed by the project targets addressing the barriers of characterization and understanding of interfacial properties of materials and electrode, which is critical to the development of all solid-state-batteries.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer noted a very impressive number of accomplishments on developing a thin solid-state battery and the tools to evaluate.

Reviewer 2:

The reviewer highlighted the focus on key issues, such as where and when voids form, how interlayers protect cell components, and how these factors depend on voltage and cycling. The reviewer applauded the micro cell and nano cell fabrication with good performance.

Reviewer 3:

The reviewer indicated that the PI succeeded in fabricating the proposed air-free vessel and micro-/nano-cells that faithfully follow the electrochemistry of conventional bulk cells. The reviewer added that the in-situ cell design and multimodal characterization have already yielded lots of scientific insights and a series of publications including several in high profile journals.

Reviewer 4:

The reviewer reported that the project team developed an air-free transfer chamber, and demonstrated that it can tape cast 50-micron free standing films of Li_6PS_5Cl electrolyte and can produce NMC/electrolyte/Li cells that cycle between 2 and 3.7 V. The reviewer noted that the chamber contains a micro cell mount that can be heated and used to apply pressure to the cell. The reviewer stated that the team is able to perform SEM and Raman measurements of the same cell in the same location with these two different instruments. The reviewer commented that plasma FIB allows for tomography of electrode, and that time of flight (TOF)-secondary ion mass spectrometry (SIMS) reveals the chemical information of interfacial reaction products and spatial distribution. The reviewer commented that the nanoindentation reveals mechanical property changes of the PTO and LPSCl domains, which causes the structure inversion.

Reviewer 5:

The reviewer stated that preliminary results appear promising.

Reviewer 6:

The reviewer expressed that the project is well on track, with the project team successfully developing an air-free vessel and multiple cell designs to characterize solid-state batteries, and that some proof-of-principle data were also collected. The reviewer asked why the solution-processed Li_6PS_5Cl solid electrolyte shows a higher ionic conductivity than the bulk solid electrolyte without solution processing. The reviewer remarked that it is usually observed that the solution processing will decrease the ionic conductivity.

Reviewer 7:

The reviewer stated that the designed air-free vessel integrated with in-situ test platform is a necessarily required and powerful tool to understand the interfaces of the electrodes and materials by eliminating the air exposure or other contaminations. The reviewer remarked that the functionalities of the device have been validated experimentally to provide useful chemical, structural and mechanical information. The reviewer added that the nano-cell design is unique and a nice platform for fundamental understanding of the Li/SSE and cathode interfaces. The reviewer said that the electrochemical performance of the thin solid NMC/SE/Li-In and NMC/SE/Li cells looks promising, but that the mass loading and content of the active NMC in the electrodes were not provided.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer remarked that the collaboration is with national laboratories plus industry–best collaboration this reviewer has seen.

Reviewer 2:

The reviewer stated that the PI is collaborating effectively with a number of organizations.

Reviewer 3:

The reviewer mentioned that the project team's collaborations include three national laboratories (PNNL, SLAC, and NREL), three universities (Rice, Brown, and University of Houston), and three companies (Ampcera, ThermoFischer, and Solid Power).

Reviewer 4:

The reviewer noted that the collaborations are extensive.

Reviewer 5:

The reviewer remarked that the team has a strong collaboration with multiple institutions from national laboratories, universities, and industry.

Reviewer 6:

The reviewer stated that the PI collaborated with national laboratories, universities, as well as U.S. industries, and that areas of collaboration range from theory, experiment, to electrolyte/cell processing.

Reviewer 7:

The reviewer indicated that the PI has close collaborations with universities, national laboratories, and industries covering tool development, materials, processing, and simulation.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer said that the proposed future research is appropriate.

Reviewer 2:

The reviewer noted that Tasks 2, 3, and 4 are well defined.

Reviewer 3:

The reviewer commented that the PI proposes several directions in future research, all of which are relevant to key scientific problems in solid electrolyte, such as mechanical property, chemical degradation mechanism, and interphase evolution.

Reviewer 4:

The reviewer stated that the project has effectively planned future work, as the team will use the developed tools/platform to study the chemical, structural and mechanical properties of the solid cells.

Reviewer 5:

The reviewer commented that the future work is to now use the instrument on a cell and fully characterize the interface between the ceramic and the active material during operation.

Reviewer 6:

The reviewer recommended that the project team carefully look at the design for the nano cell. The reviewer added that because of the significant decrease in the area of the cell, based on the current design, the resistance from only the ionic conduction in the electrolyte layer will be too large to enable any meaningful electrochemical test.

Reviewer 7:

The reviewer remarked that there is great promise, but a real challenge to integrate all of the information that the project team will get into a coherent picture.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer indicated that this is exactly the type of work that the DOE should support as it will help further the progress of solid-state batteries regardless of chemistry under evaluation.

Reviewer 2:

The reviewer commented that the DOE believes an investment in solid state is part of its mission and this company is developing important tools to investigate developments.

Reviewer 3:

The reviewer remarked that the air-free vessel can be used for in situ characterization of various materials critical to achieving the DOE objectives.

Reviewer 4:

The reviewer acknowledged that this effort will lead to a better understanding of the degradation and failure mechanisms of solid-state batteries.

Reviewer 5:

The reviewer applauded the great effort to make fundamental measurements on well-characterized cells.

Reviewer 6:

The reviewer stated that this project supports the overall DOE objectives in providing clean energy solutions, specifically, the beyond Li-ion battery option that has higher energy density and better safety characteristics than the conventional liquid electrolyte-based Li-ion batteries.

Reviewer 7:

The reviewer mentioned that this project is well aligned with DOE/VTO's objective of vehicle electrification, particularly when it comes to the development of next generation high energy all-solid-state Li batteries.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer indicated that the project is appropriately funded.

Reviewer 2:

The reviewer mentioned that the team's progress has been excellent.

Reviewer 3:

The reviewer remarked that the team has sufficient resources for the project.

Reviewer 4:

The reviewer acknowledged that the resources are sufficient.

Reviewer 5:

The reviewer noted sufficient resources.

Reviewer 6:

The reviewer noted that the resources for the project are sufficient to achieve the stated milestones in a timely fashion.

Reviewer 7:

The reviewer reported that the PI and team have sufficient resources to achieve the stated milestones in a timely fashion.

Presentation Number: bat490
Presentation Title: First-Principals Modeling of Cluster-Based Solid Electrolytes
Principal Investigator: Puru Jena (Virginia Commonwealth University)

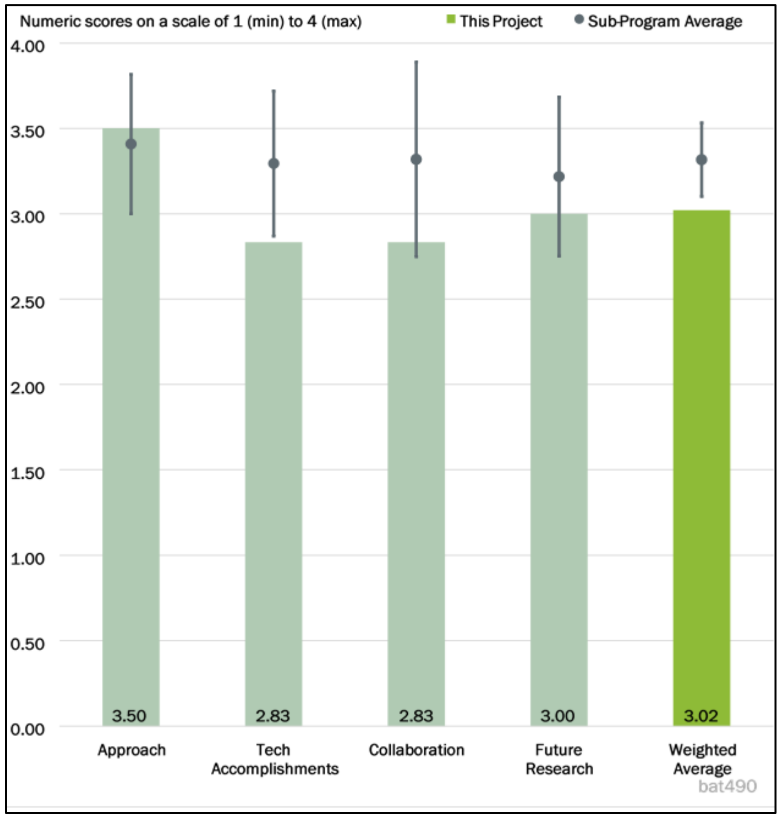


Figure 2-46 - Presentation Number: bat490 Presentation Title: First-Principals Modeling of Cluster-Based Solid Electrolytes Principal Investigator: Puru Jena (Virginia Commonwealth University)

Presenter

Puru Jena, Virginia Commonwealth University

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 67% of reviewers felt that the resources were sufficient, 33% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer noted the novel approach to identify and design cluster-based compounds for solid electrolytes with the first principle calculation.

Reviewer 2:

The reviewer commented on the interesting, bold and novel approach where single atom sites are substituted with a cluster of ions larger in size and more electronegative, but stable as well. The reviewer added that the modeling screening approach is appropriate and efficient, as new compositions have been proposed.

Reviewer 3:

The reviewer indicated that overall, the approach appears good. The reviewer added that the presence of three partners who appear to have experimental roles is a major positive, and that relevant materials appear to be under investigation.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer commented that the project team has established a database of predicted cluster-based structures that are potentially suitable for solid electrolytes. The reviewer added that ion conductivity, bandgap, and activation energy are calculated for all the materials in the database.

Reviewer 2:

The reviewer remarked that low level theory methods were used to initiate the search for new compositions (clusters), followed by DFT calculations and feedback loop for optimization. The reviewer mentioned that the computational cost seems to be mostly due to the calculation of diffusivities, otherwise just simple energy relaxation of bulk compositions. The reviewer noted the efficient approach for fast results.

The reviewer posed a few questions about the presentation.

- Other than energy calculations, how can one assess if the predicted compositions/formulations can be synthesized?
- What are the major criteria for choosing the cluster, other than activation energy (E_a) and ionic size?
- Total energy of the chemically mixed structure is found to be increasing linearly with the increasing concentration of the cluster-ions being substituted by atomic ions. In response to question of how the team calculates the "Probability distribution function," the presenter answered, "Molecular dynamics," to which this reviewer asked if this was not expected.
- How does the point-charge electrostatic model compare with the DFT optimization? How confident is the project team about the screening process based on point charges being complete?
- Can the project team elaborate on the following statement, "Established model based on the local topology of the anion-mediated Li-transport"?
- How is the activation barrier for Li transport estimated? From AIMD?
- Why Particle swarm optimization? Other, more reliable programs exist.

Reviewer 3:

The reviewer stated that the milestones are not quantitative so it is hard to assess the significance of the progress. The reviewer did not see any experimental results in the deck, and noted that it is unclear what challenges the experimental partners are having, and whether the connection with experiments will in fact take place in the project, and if it will be a strong and productive connection.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted that the team has collaborations with national laboratories and other universities on materials synthesis and characterization.

Reviewer 2:

The reviewer remarked that three different institutions are mentioned as partners for synthesis and characterization. The reviewer added that so far, only computational results are shown, but that it is understood that the computational screening comes first followed by synthesis of the proposed compositions afterwards.

Reviewer 3:

The reviewer stated that it is excellent that there are partners, but it is unclear what the connections are and the significance of the output based on the slides presented.

Question 4: ***Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.***

Reviewer 1:

The reviewer noted that in order to further down select the best candidates for the solid electrolytes, the team needs to characterize the interface stability. The reviewer added that it is very important to provide guides on how to synthesize the predicted materials.

Reviewer 2:

The reviewer stated that the proposed computational work is in-line with the project goals. The reviewer indicated that the experimental confirmation via synthesis of the best proposed compositions is mentioned in the remaining challenges section, but not in the future work.

Reviewer 3:

The reviewer commented that relevant future work is listed, but that without quantitative milestones or more specific descriptions around the connection with experiments, it is hard to know whether the deficiencies mentioned above will be addressed in future work.

Question 5: ***Relevance—Does this project support the overall DOE objectives? Why or why not?***

Reviewer 1:

The reviewer stated that the project is working on solid electrolyte materials, which fits into DOE objectives.

Reviewer 2:

The reviewer mentioned that the study provides a fundamental understanding of the cluster-based structures and their suitability for high-performance solid electrolytes. The reviewer indicated that this may spawn inventions of novel solid electrolytes for ASSBs.

Reviewer 3:

The reviewer stated that screening for new and novel solid-state electrolytes using computational techniques supports the overall DOE objectives.

Question 6: ***Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?***

Reviewer 1:

The reviewer noted that the team has sufficient resources for the targeted works.

Reviewer 2:

The reviewer stated that the amount of work and effort needed to better explore the available space for new electrolytes using computational approaches (manpower), and the experimental validation of the proposed compositions might require more funding.

Reviewer 3:

The reviewer remarked that Slide 2 mentions a $33,000 budget for FY 2020, and asked if it is a typo. The reviewer added that if it is not, then it looks like the team is struggling to spend the funding.

Presentation Number: bat491
Presentation Title: Predictive Engineering of Interfaces and Cathodes for High-Performance All Solid-State Lithium-Sulfur Batteries
Principal Investigator: Badri Narayanan (University of Louisville)

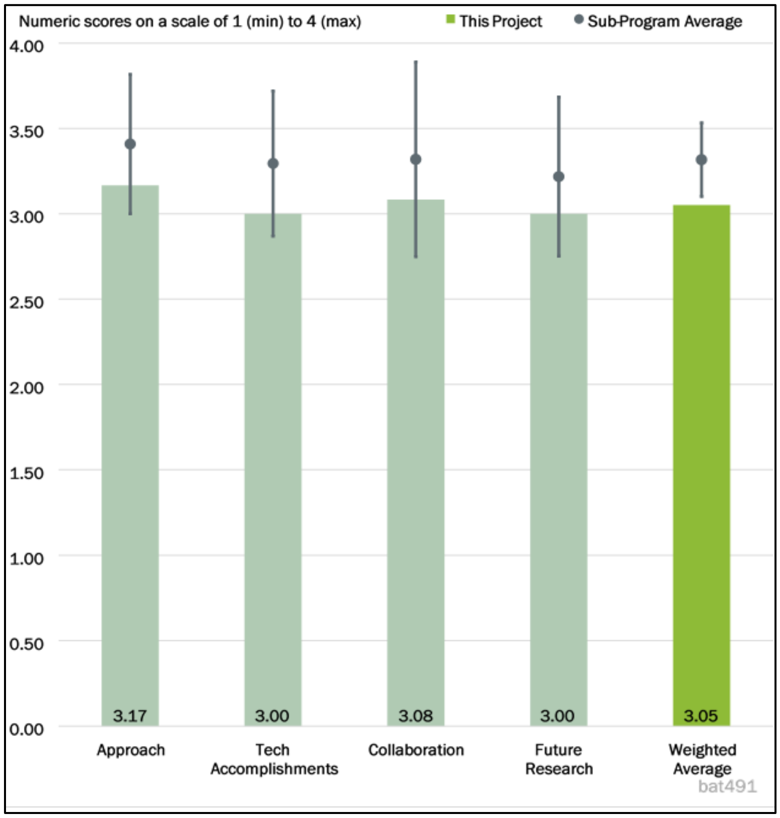


Figure 2-47 - Presentation Number: bat491 Presentation Title: Predictive Engineering of Interfaces and Cathodes for High-Performance All Solid-State Lithium-Sulfur Batteries Principal Investigator: Badri Narayanan (University of Louisville)

Presenter

Badri Narayanan, University of Louisville

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 17% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that there is a nice combination of modeling and experimental work. The reviewer added that most of the technical barriers have been addressed, and that the project is feasible though challenging.

Reviewer 2:

The reviewer noted that a number of computational approaches including first principles, kinetic Monte Carlo, and atomistic modeling are proposed to achieve atomic-scale understanding of transport, reactions, and materials evolution in solid-state lithium-sulfur batteries. The reviewer indicated that experimental efforts were also proposed to validate the computational results. The reviewer remarked that these fundamental studies will lead to a better understanding of key challenges in solid state batteries. The reviewer explained that Lithium argyrodite was used as the solid electrolyte system and mesoporous sulfur was used as the cathode. The reviewer said that the project team proposed to use ionic liquid based catholyte in the cathode composite. The reviewer mentioned that previous efforts have shown many important attributes of solid-state batteries can be compromised by incorporating liquid electrolytes. The reviewer concluded by saying that all solid-state lithium sulfur batteries without any liquid electrolyte have also been demonstrated by many research groups.

Reviewer 3:

The reviewer indicated that Li-S batteries have numerous problems to overcome, including requirement for large amounts of dioxolane (DOL). The reviewer was not sure how the authors plan to deal with this. The reviewer was not convinced that MD calculations on such short time and space scales are sufficient to determine reactivity.

Reviewer 4:

The reviewer stated that the PI focuses on solid state Li-S battery and uses theoretical modeling to guide the composition optimization of argyrodite ($Li_{6+y}P_2S_{8-y}X_y$, where X can be Cl or F) solid electrolyte and to gain fundamental understanding about the interphase. The reviewer added that the PI also uses ionic liquid to address the interfacial contact issue between solid electrolyte and sulfur cathode. The reviewer indicated that these are addressing key issues facing solid state lithium-sulfur batteries.

Reviewer 5:

The reviewer remarked that the proposed approaches are comprehensive and cover materials synthesis, cell test, and theoretical simulation. The reviewer stated that this project targets at the interfaces and cathodes of all solid-state Li-S battery, but the proposed approach is actually an integration of ionic liquid electrolyte, additional solvents and Argyrodite solid electrolytes. The reviewer concluded that would make the system more complicated due to the chemical compatibility issues of solid electrolyte with ionic liquid and especially the ether solvents.

Reviewer 6:

The reviewer remarked that getting Li/S to work is a major challenge. The reviewer reported that the approach here is to use AIMD to determine the best anion substitution in a LiPSX sulfide electrolyte for improved conductivity and stability, after which the project team synthesized the electrolyte and built a cell.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer stated that the modification of the solid electrolyte led to greatly improved performance. The reviewer indicated that this was a good demonstration of combined modeling and experimental work. The reviewer added that the system will be rather challenging to achieve high energy density because of the poor electronic conductivity of S which makes high loading problematic.

Reviewer 2:

The reviewer commented that the project team was very successful in identifying an electrolyte with higher conductivity and better stability. The reviewer acknowledged that the team has a pretty good handle on the mechanism of conduction and reaction with lithium. The reviewer reported that the team successfully synthesized the electrolyte, and built a cell with the chosen electrolyte, with the cathode being 35% sulfur by weight. The reviewer was not sure of the porosity of the cathode, as the team added an ionic liquid to the cathode for ionic conduction. The reviewer noted that the cell starts at 300 mAh/g and ends at 200 mAh/g after 100 cycles. The reviewer stated that the team added DOL to the cathode and improved the capacity to 800 mAh/g at beginning of cycling and finished at 500 mAh/g at cycle 100. The reviewer added that the cell had an overall capacity of 0.5 mAh/cm^2, and that the initial work was interesting but the final cell build was not very impressive.

Reviewer 3:

The reviewer remarked that the project team identified F-doping as an effective approach to improve the ionic conductivity of Li argyrodite solid electrolytes. The reviewer noted that it is surprising to see long-range motion of F ions in the Li_6PS_5F electrolyte as the ionic conductivity of F anion in solids is typically very low. The reviewer mentioned that more detailed characterizations are needed to confirm successful substitution of F in the solid electrolytes. The reviewer added that the interfacial stability between solid electrolyte was also studied in Li-Li symmetrical cells, but the current densities are still limited to 0.15 mA/cm^2. The reviewer indicated that Li-S full cell with ionic liquid in the cathode was also tested, and the performance of the full cell are still limited. The reviewer reported that some voltage noise can be observed during charging processes.

Reviewer 4:

The reviewer noted that the project team can make any mixture of halogens in the LPS using a low-cost scalable technique, leading to improved conductivity. The reviewer added that combined with the theoretical understanding, this is a very valuable result. The reviewer wondered if this sort of thinking can be extended to other SEs.

Reviewer 5:

The reviewer stated that the PI shows that modeling guided solid electrolyte optimization, especially in maximizing ionic conductivity, succeeded in synthesizing solid electrolyte with designed composition. The reviewer remarked that the PI also made great progress in developing models for studying the interphases between electrolyte and cathode/anode. The reviewer indicated that full cells consisting of sulfur-carbon cathode, ionic liquid (improving the contact), solid electrolyte, and lithium metal anode are tested and show promising performance. The reviewer noted that the PI also showed good publication record.

The reviewer reported that the cathode loading which is around 1mg/cm^2 needs to be improved. The reviewer observed that the shaky electrochemical curve during the charging stage needs to be addressed. The reviewer added that the PI addresses the interfacial contact issue between solid electrolyte and cathode using ionic liquid. The reviewer asked about the contact between electrolyte and lithium metal anode, and mentioned that this may also need to be addressed.

Reviewer 6:

The reviewer remarked that the F co-doped Argyrodite solid electrolytes developed under this project has much lower ionic conductivity and Li critical current density if compared with other reported Cl- or Br- based Argyrodite electrolytes. The reviewer added that the compatibility of the solid electrolyte with ionic liquid and solvents is an important factor to the cell cycling stability, but that it was not studied in this project. The reviewer noted that sulfur loading in the electrode is too low to evaluate the effectiveness of the approach, and that sulfur utilization rate is very low, even when excess amount of liquid electrolytes were used in the cell.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted that the team worked well together to combine modeling and experimental research.

Reviewer 2:

The reviewer stated that this was a multi-PI project with all PIs at the University of Louisville that collaborated with top modelers at Argonne.

Reviewer 3:

The reviewer noted that all work was done at the University of Louisville, but that new collaborations with ANL and ORNL will improve collaboration.

Reviewer 4:

The reviewer reported that the PI collaborated with both national laboratories and universities.

Reviewer 5:

The reviewer expressed that the PI has good collaboration across the universities and national laboratories. The reviewer added that the PI indicated collaborations with Oak Ridge National Laboratory on neutron diffraction analysis, but no such results were included in the report.

Reviewer 6:

The reviewer remarked that it was all done at the same institution, and encouraged collaborations with other institutions.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer stated that the proposed work is on target, and that particularly focusing on higher loading is important for testing the viability.

Reviewer 2:

The reviewer remarked that the PI proposed several important directions for future research, including increasing sulfur loading and decreasing the amount of ionic liquid.

Reviewer 3:

The reviewer acknowledged that the project has a clear plan for future work. The reviewer indicated that chemical compatibility between the solid electrolyte and liquid parts should be considered in future research, and that design and optimization of the high loading sulfur electrode architecture should be a focus.

Reviewer 4:

The reviewer mentioned that future work lists a number of modeling tasks to better understand the conductivity, which will unlikely lead to improved cell capacity or capacity retention.

Reviewer 5:

The reviewer noted that almost all of the future work involves theory, and that this does not seem balanced.

Reviewer 6:

The reviewer indicated that the project team needs to study in detail the failure mechanisms of Li-S full cells. The reviewer added that the voltage noises or spikes during charging are unlikely caused by kinetics as is proposed by the team. The reviewer reported that Polysulfide shuttle or lithium dendrite shorting can also lead to similar voltage spikes. The reviewer suggested that more characterizations including both electrochemical and materials characterizations should be done to understand the underlying cause. The reviewer encouraged the team to also study the cathode electrolyte interface in an all-solid-state setup, as the addition of ionic liquid electrolytes in the cathode composite does not seem to help much on the kinetics.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer stated that a functioning high energy Li-S clearly would meet many of the DOE objectives owing to the great abundance of S and low cost.

Reviewer 2:

The reviewer remarked that this project will enable the development of solid-state Li sulfur batteries.

Reviewer 3:

The reviewer indicated that this project supports the overall DOE objectives in providing clean energy solutions, specifically, the beyond Li-ion battery option that has higher energy density and better safety characteristics than the conventional liquid electrolyte-based Li-ion batteries.

Reviewer 4:

The reviewer said that this project focuses on solid-state Li-S battery, which is a promising energy storage technology and aligns well with DOE/VTO's objective of vehicle electrification.

Reviewer 5:

The reviewer noted that DOE still considers Li/S a viable technology for improving battery energy density. The reviewer added that this work was mainly helpful in developing techniques for establishing better electrolytes, and that the overall system has a long way to go.

Reviewer 6:

The reviewer expressed that Li-S cells with solid electrolytes are not in the mainstream, and that the use of ionic liquids is problematic at lower temperatures. The reviewer added that while using SEs avoids the Li sulfide shuttle—perhaps the biggest problem with cells that use liquid electrolytes—it's not clear that using SEs makes the situation any better in terms of performance.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted that the project is appropriately funded.

Reviewer 2:

The reviewer stated that the resources are sufficient.

Reviewer 3:

The reviewer commented that the resources for the project are sufficient to achieve the stated milestones in a timely fashion.

Reviewer 4:

The reviewer observed that the PI's team has sufficient resources and capabilities to perform the proposed research.

Reviewer 5:

The reviewer expressed that it is impressive that this group of professors were able to come up with 20% cost share to be matched with $1,000,000 from DOE, and added that the project will need a lot more money to advance this system.

Reviewer 6:

The reviewer remarked described project resources as barely adequate, and that the addition of ANL and ORNL will be important.

Presentation Number: bat492
Presentation Title: Machine Learning for Accelerated Life Prediction and Cell Design
Principal Investigator: Eric Dufek (Idaho National Laboratory)

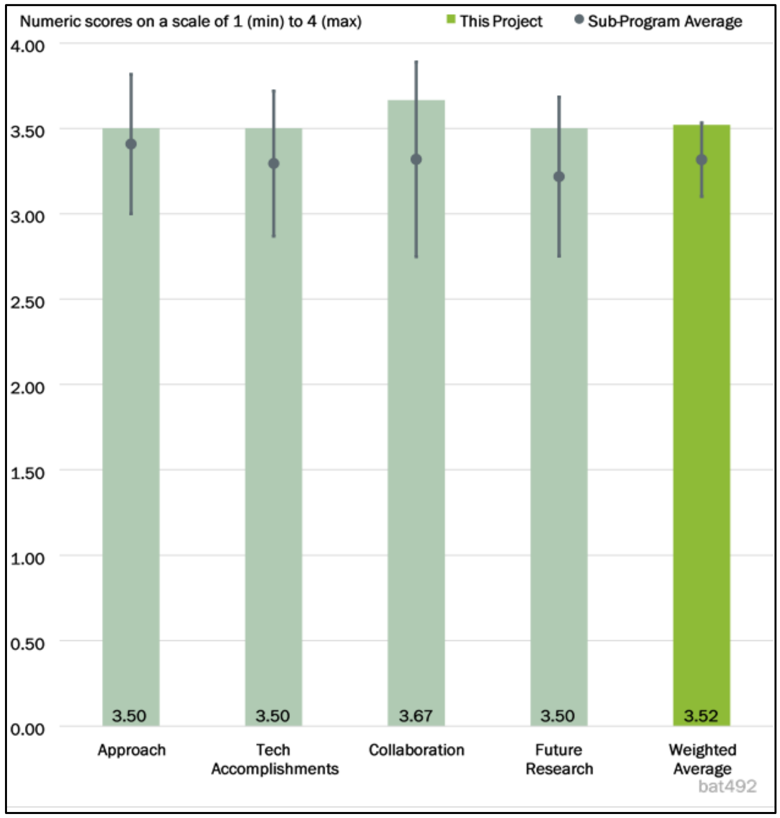


Figure 2-48 - Presentation Number: bat492 Presentation Title: Machine Learning for Accelerated Life Prediction and Cell Design Principal Investigator: Eric Dufek (Idaho National Laboratory)

Presenter

Eric Dufek, Idaho National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that the program is very well defined and the approach is robust.

Reviewer 2:

The reviewer noted that the approach involves machine learning to accelerate the cycle life prediction of batteries including capturing degradation mechanisms through logistic regressions. The reviewer commented that the milestone lists “initiate Deep Learning related to electrochemical signatures”, while current models are mostly shallow learning models. The reviewer indicated that there may not be a need to do deep learning, but that it would be good to check and show that shallow learning models work well enough.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer stated that the work done so far shows very clearly the potential for ML-based methods to perform early life prediction and fast charging. The reviewer mentioned that the current work has used synthetic data and used ML models to identify the signatures. The reviewer noted that the team has used other data to provide initial results, which provides confidence that these approaches are likely to work well.

Reviewer 2:

The reviewer commented that the progress so far has been impressive, and suggested emphasizing on graphite/NMC chemistry rather than spending more resources on LTO/LMO chemistry. The reviewer asked the project team to try to use data from USABC projects for various chemistries including silicon-based anode. The reviewer explained that there is lot of cycle life, calendar life, and lately fast charging cycling data that will be helpful to develop models and validate.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer said that the team is well-balanced and brings excellent complementary expertise. The reviewer observed that the team has also been extending their collaboration network outside very effectively.

Reviewer 2:

The reviewer suggested establishing a collaboration with Stanford University possibly in the area of manufacturing processes and new materials development, as some work has been published by that group. The reviewer added that it will be very useful to involve cell developers at the earliest possible so that methods could be verified and validated with a larger set of data and latest chemistry.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer acknowledged that the proposed project plan is sound. The reviewer remarked that the process for collaboration of data will be a key development activity that will be broadly useful, and that setting the right practices in place would be crucial.

Reviewer 2:

The reviewer suggested to include, define, and start working on manufacturing processes related work. The reviewer observed that it is mentioned on “Relevance Objective” Slide 3, but that there is no defined work for this objective.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer mentioned that reducing overall battery cost via reduction in cell validation cost, materials development, cell design and manufacturing are very important objectives to go after, and will help the battery industry significantly.

Reviewer 2:

The reviewer expressed that the program clearly helps in accelerating the prediction of performance, reducing time to predict, and understanding failure modes.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted that the team is staffed at the right level to deliver the milestones.

Reviewer 2:

The reviewer commented that it may be worthwhile to assess resources after mid-way through to add more resources rather than after two full years of the project at the next AMR review.

Presentation Number: bat493
Presentation Title: WPI USABC LCFC Project
Principal Investigator: Yan Wang (WPI)

Presenter

Yan Wang, WPI

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers felt that the resources were sufficient, 20% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

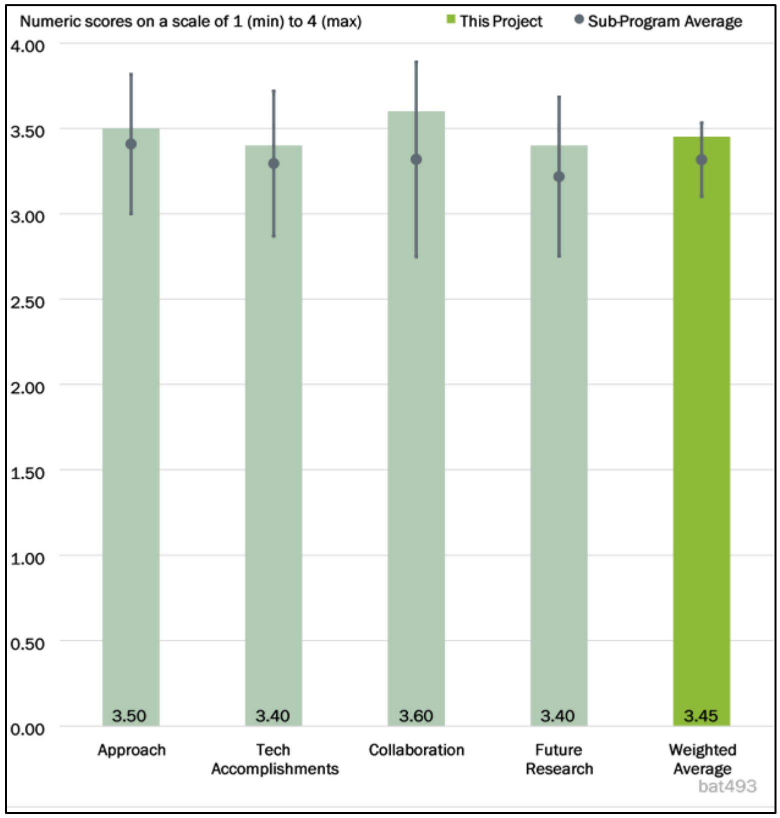


Figure 2-49 - Presentation Number: bat493 Presentation Title: WPI USABC LCFC Project Principal Investigator: Yan Wang (WPI)

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer noted that the efforts addressed the high energy battery fast charging need through an interesting approach on solvent-free manufacturing method for hetero-structured cathodes and anodes.

Reviewer 2:

The reviewer remarked that low-cost Li-ion cells can and should be achieved not only through low-cost material development but also through low-cost manufacturing. The reviewer added that in these regards, this project took a very relevant approach.

Reviewer 3:

The reviewer expressed that the tasks are well-designed to meet the objectives, and that a comprehensive cost analysis of the new approach to fabricate the electrode will be helpful.

Reviewer 4:

The reviewer observed that ion conduction and resistance are intrinsic properties of the electrode, and added that tailoring them can provide a viable pathway to a fast-charging electrode. The reviewer indicated that the two-layer approach can help to solve the transport problems and still provide a decent mass loading combined with fast-charge properties.

Reviewer 5:

The reviewer mentioned that the approach is to use a novel dry casting method to fabricate electrodes. The reviewer added that active material/binder/carbon is spray cast without a solvent onto a current collector and then calendared with a heated roller to ensure appropriate binding. The reviewer observed that the electrodes are prepared and characterized at various C-rates, then compared to electrodes made using a more traditional slurry casting technique. The reviewer reported that modeling is also performed to understand appropriate electrode porosity, and that the project appears well-designed and feasible. The reviewer expressed concern that the modeling appears to have focused on the elucidation of a "dual" porosity electrode architecture, and it is not clear how these results would inform dry-spray electrode fabrication. The reviewer asked if there are plans to develop "graded/layered" electrodes?

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer liked all the aspects of this work, and remarked that it was well balanced among process, modeling, experiment. The reviewer affirmed that the work was well planned and organized, and that cell performance of solvent-free electrodes is impressive. The reviewer recommended more rigorous evaluation such as power characteristics, high temperature storage, and calendar life.

Reviewer 2:

The reviewer observed that the dry spray method looks promising, and said that it will be more convincing if the yield is reported (the percentage of the sprayed powders that stay on the electrode).

Reviewer 3:

The reviewer indicated that the progress so far is good, and that it will be interesting to see the extended lifecycle tests of the cells. The reviewer added that it would be great to provide an estimation of the technology in Wh/L and Wh/kg on the cell level, combined with a sensitivity analysis (how much specific energy density loss provides how much percent improvement in fast charging). The reviewer suggested that the calendric aging and DCIR rise are two other points to consider in the progress of the project.

Reviewer 4:

The reviewer stated that the modeling is very interesting and clearly shows the benefit of a layered porosity electrode architecture. The reviewer added that dry sprayed electrodes have been prepared and have similar, or perhaps a bit better, performance than conventional slurry-cast electrodes, which is a great result that could lower fabrication costs rather significantly if fully developed. The reviewer concluded that this project appears to be making great progress.

Reviewer 5:

The reviewer stated that progress in modeling and solvent-free manufacturing were as scheduled. The reviewer added that it was demonstrated that the cell with electrodes made with solvent-free manufacturing technique has relatively better fast charging capability compared to that with the cell electrode made with wet processing. The reviewer noted that it is not fully clear how many cells were produced to generate the testing results, and that the limited number of cells may not be sufficient to demonstrate the properties of the cell produced with the developed solvent-free technique.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer stated that collaborations among team members are excellent.

Reviewer 2:

The reviewer observed that collaboration partners are well selected and coordinated, and that the contribution of each partner is very clear.

Reviewer 3:

The reviewer noted that ANL and Microvast test batteries using the solvent-free electrode made by the team.

Reviewer 4:

The reviewer noted that having an established company building and providing the cells for the tests clearly helps the pace of the project, and that it might be beneficial to include some partners with a deep analytical understanding of the SEI and electrolyte compositions.

Reviewer 5:

The reviewer indicated that the collaboration between WPI, Rice University, Microvast, and Texas A&M University (TAMU) is working really well with all collaborators appearing to have clearly defined roles and making good progress as a team.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer noted that future research is nicely planned.

Reviewer 2:

The reviewer remarked that the project will benefit from the extended lifecycle tests, and highlighted other points to consider such as multilayer pouch cells; DCIR system investigation; and electrolyte variation. The reviewer added that a cost estimation of process should be carried out in order to proof its applicability.

Reviewer 3:

The reviewer reported that future work focuses on pouch cell fabrication and evaluation. The reviewer expressed interest in seeing whether the team can make the “dual porosity” electrodes that the modeling has clearly shown to be effective at improving fast charge capability.

Reviewer 4:

The reviewer agreed with all the proposed future research, yet encouraged the team to expand this effort to double side coating and multi-layer pouch cells. The reviewer recommended more rigorous cell characterization.

Reviewer 5:

The reviewer stated that future work is properly illustrated, and that it will be interesting to know if the solvent-free technique is applicable to multi-layer pouch cell manufacturing. The reviewer added that the technology transition plan of the developed technique is not very clear, and suggested that the contractor reaches out to potential partners for battery manufacturing at the end of this project.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer stated that the objective of this project to develop low-cost batteries capable of fast charging for EV applications supports DOE goals.

Reviewer 2:

The reviewer affirmed that this project is very relevant to the DOE goal to develop low-cost Li-ion cells.

Reviewer 3:

The reviewer observed that this project supports the overall DOE objectives by avoiding solvents in the manufacturing of lithium-ion battery electrodes.

Reviewer 4:

The reviewer indicated that this project fully supports the DOE objectives.

Reviewer 5:

The reviewer commented that dry spray casting could dramatically reduce the environmental impacts of battery manufacturing, which makes this project directly applicable to DOE's objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer stated that resources appear sufficient for this project.

Reviewer 2:

The reviewer noted that the funding level is appropriate for the project.

Reviewer 3:

The reviewer suggested giving more resources to the team so it can develop larger scale equipment and multi-layer pouch cell via double side coating.

Reviewer 4:

The reviewer remarked that the project would benefit from collaboration with equipment manufacturers.

Reviewer 5:

The reviewer said that the resources seem to be sufficient, even a bit on the low side for the proposed work.

Presentation Number: bat494
Presentation Title: Microvast USABC LCFC Project
Principal Investigator: Wenjuan Mattis (Microvast)

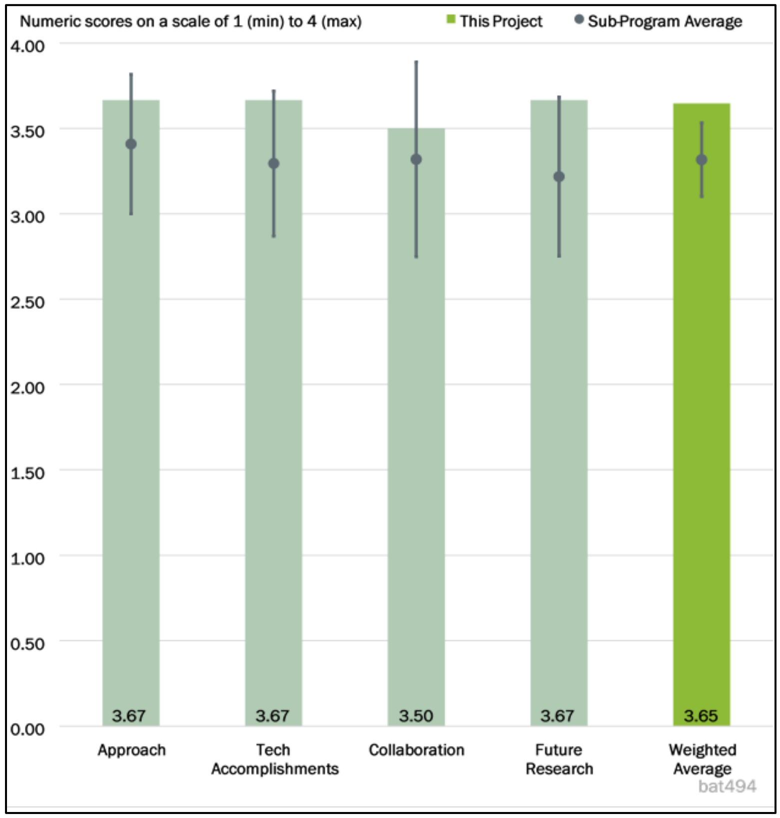


Figure 2-50 - Presentation Number: bat494 Presentation Title: Microvast USABC LCFC Project Principal Investigator: Wenjuan Mattis (Microvast)

Presenter

Wenjuan Mattis, Microvast

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer observed that novel full concentration gradient low-Co cathode materials and additives for Lithium-ion battery fast charging have been addressed in this project. The reviewer noted that several interesting approaches were proposed and/or developed appropriately, including the employment of a graphite/Si based alloy.

Reviewer 2:

The reviewer mentioned that the tasks are well-designed to meet the objectives, and that the combination of the Aramid separator, FCG cathode, and electrolyte additive is innovative.

Reviewer 3:

The reviewer said that the approach to this program is to develop low-Cobalt (less than 2.5 wt%) gradient materials to reduce cathode material price, and combine them with an additive that improves the rate capability of cells that employ the gradient material. The reviewer added that electrochemical characterization and cycle lifetime assessment are primarily used for characterization. The reviewer stated that the project has very well-defined goals and that given the year one progress, those goals appear very achievable.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer observed that performance targets have been met so far.

Reviewer 2:

The reviewer remarked that great progress has been made, with the materials development completed for both the gradient active material and lab-scale quantities of the additive prepared. The reviewer added that the gradient material has high cycle life in a 260 Wh/kg pouch cell, although targeted cost still needs to come down a bit. The reviewer mentioned that the additive also appears to allow very good repeated fast charging, with 60% capacity retention after 700 2.5C charging cycles.

Reviewer 3:

The reviewer expressed that progress for year one is impressive, and that the proposed milestones were met. Another effort funded by DOE for the calendar life testing was also suggested: https://www.nrel.gov/transportation/assets/pdfs/silicon-calendar-life-report-04012021.pdf.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer stated that the contractor has a good collaboration with the INL testing team, and that research progress has been properly reported to the USABC program manager.

Reviewer 2:

The reviewer observed that Idaho National Laboratory helps on the testing protocols.

Reviewer 3:

The reviewer noted the collaboration with INL, which has helped with cell analysis, and USABC.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer stated that the proposed future study is reasonable.

Reviewer 2:

The reviewer indicated that future research is nicely planned, especially on improving the energy density.

Reviewer 3:

The reviewer observed that future work will focus on integrating Si into the anode to boost energy density, and that the additive will also be studied to understand its influence on the SI anode. The reviewer concluded that these are reasonable directions that should result in improved energy density.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that the project supports DOE goals by working to improve Li ion battery sustainability by potentially eliminating the use of cobalt in the cathode electrode, lower costs, address energy security questions regarding cobalt, improve the accessibility of electric vehicle ownership, facilitate fast charge to address range concerns, and lower costs to make them more affordable.

Reviewer 2:

The reviewer noted that this project supports the overall DOE objectives by reducing the cost and improving the performance of lithium-ion batteries.

Reviewer 3:

The reviewer said that yes, the development of low cobalt and fast charging materials are both directly related to DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer stated that the funding level is reasonable for the scheduled work.

Reviewer 2:

The reviewer indicated that resources appear sufficient for the project.

Reviewer 3:

The reviewer observed that the diagnosis part of the project would benefit from working with a university partner.

Presentation Number: bat495
Presentation Title: AMO/VTO FOA Award Applied Materials
Principal Investigator: Ajey M. Joshi (Applied Materials)

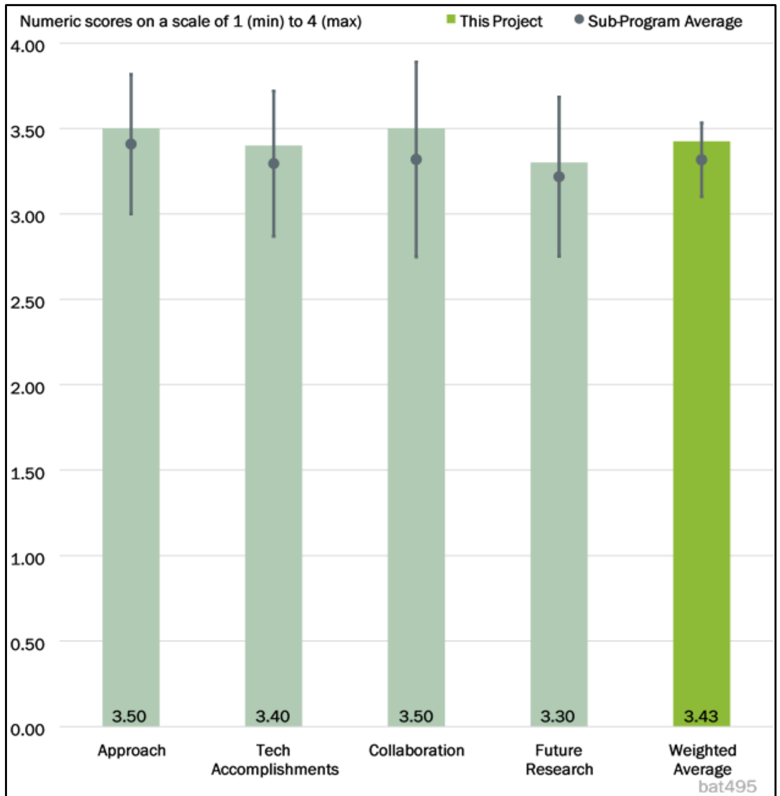


Figure 2-51 - Presentation Number: bat495 Presentation Title: AMO/VTO FOA Award Applied Materials Principal Investigator: Ajey M. Joshi (Applied Materials)

Presenter

Ajey M. Joshi, Applied Materials

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 20% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer expressed that to enable low cost, low efficiency Si or SiO_x anode materials for high energy density Li-ion battery development, prelithiation is an effective route. The reviewer agreed that the proposed work addressed technical barriers well, and liked the approach of this work in terms of scaled manufacturing. The reviewer noted that for even higher energy density cell using Li metal anode, this approach is also very effective.

Reviewer 2:

The reviewer mentioned that the project leverages the unique expertise of Applied Materials and the partners to develop a Li metal evaporation process for battery applications. The reviewer observed that the tasks are well-designed to meet the objectives.

Reviewer 3:

The reviewer remarked that the approach is to develop and implement a Li metal deposition tool to prepare Li metal anode and pre-lithiated SiO_x anodes. The reviewer added that the tool has been developed, electrodes have been made and distributed to manufacturers, and the tool has been used to pre-lithiate a SiO_x-C anode, which has also been integrated into a pouch cell by a collaborator. The reviewer stated that in other words, Applied Materials (AMAT) is leveraging this unique tool to potentially advance high energy anodes.

Reviewer 4:

The reviewer expressed that the technical barriers for lithium batteries with r2r were addressed, which may pave the way for large scale battery production. The reviewer added that it is unclear if the technology to be developed is applicable to the current lithium-ion batteries with energy cells (relatively less energy density) or power cells for hybrid vehicle applications to establish domestic battery production lines.

Reviewer 5:

The reviewer stated that the program addresses some of the key barriers of high-volume manufacturing for high energy anode systems. The reviewer indicated that the technical approach is very clear, and said that it would be interesting to see a cost estimation and/or prognosis for the processes, and the costs it adds to a final cell design. The reviewer commented on the necessary overhead in the production facility, e.g., requirements for the dry room or inert atmosphere and associated costs. The reviewer suggested that approaching the suggested TRLs, these operational necessities should be clearly lined out, addressed, and minimized.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer noted that year one performance targets are met.

Reviewer 2:

The reviewer observed that progress has been made and major go/no-go milestones have been met. The reviewer remarked that for the figure to show Roll-to-Roll Li Deposition Demonstration, testing condition "Cycling: 0.33C discharge to -1.0 V, 30min rest after discharge," it seems questionable for the cell to discharge to -1.0V.

Reviewer 3:

The reviewer reported that the developed prelithiation showed energy density increase and cycle life improvement and asked if there is any limitation of Li deposition in terms of mAh/cm^2. This reviewer also inquired about the target Li deposition speed for practical application as well as the estimated cost, e.g., in $/kWh.

Reviewer 4:

The reviewer observed that some progress has been made on the way to high-energy lithium-ion cells, however the reviewer noted that the overall integration into an existing production line should be emphasized and investigated more. The reviewer mentioned that the make-or-break point of this technology will be the integration into existing equipment for lithium-ion cell production.

Reviewer 5:

The reviewer stated that all milestones are on track, and go/no-go decision points have all been "Go's." The reviewer added that the Li deposition tool has been used to make Li metal electrodes, although the cycling data shows significant fade in NMC622/Li cells. The reviewer indicated that this could of course be entirely related to the electrolyte of choice rather than the quality of Li deposited, but that it would be useful to complete an analysis on the deposited metal purity. The reviewer observed that the Li-Li symmetric cells performed much better, and that the SiO_x-C composite electrodes were also prelithiated and cycled with reasonable capacity retention.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer mentioned that the strong research team seems to have a very good collaboration among team members.

Reviewer 2:

The reviewer remarked that the collaboration is well coordinated to compliment limitations of AMAT.

Reviewer 3:

The reviewer noted that a strength of the project is the five partners from both downstream battery manufacturers and national laboratories, each contributing their strength, and highlighted that it is an organically integrated collaboration.

Reviewer 4:

The reviewer indicated that the team includes many collaborators, including Zenlabs and PNNL, who have tested SiO_x-NMC and Li metal-NMC cells, respectively, for this project. The reviewer added that LBNL, ANL, and Saft are also collaborators, which is clearly a strength of this project.

Reviewer 5:

The reviewer stated that the team is well set up, but that interactions between partners are not made clear.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer stated that the barriers for future work have been identified, and that future work for next budget period was illustrated, but not in detail. The reviewer asked if there is any possibility for this project to demonstrate the manufacturing technique on large battery cells (e.g., greater than 10Ah) such as those that can be used for electric vehicles.

Reviewer 2:

The reviewer noted that the future research direction is well proposed in terms of cost, scaling, and validation.

Reviewer 3:

The reviewer remarked that the future research is nicely planned, especially on the scale up of roll-to-roll manufacturing.

Reviewer 4:

The reviewer mentioned that future work focuses on using the Li deposition tool to scale up to larger cells, and to improve the tool to increase output and allow roll-to-roll manufacturing. The reviewer added that these directions seem reasonable if this technology can improve the state-of-the-art performance anode materials. The reviewer noted that Li metal will still have its challenges regardless of the outcome of this project, and initial data for SiO_x-C cycling capability looks comparable to materials that are not prelithiated.

Reviewer 5:

The reviewer expressed that the proposed future research is okay, and that a strong emphasis on the cost estimation and process parameters, e.g., atmosphere in which pre-lithiation foil can be handled, added costs for the production, etc. should be considered. The reviewer stated that a calculation of how the pre-lithiation dose influences the lithium inventory in the cell and how this affects the amount of cathode material needed for cell would also be highly appreciated.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer stated that the objectives of this project—to advance batteries with prelithiated SiO_x-C anodes with energy density greater than 337Wh/kg from TRL 5 to TRL 7, to advance batteries with Li-metal anode with energy density greater than 375Wh/kg from TRL 4 to TRL 6, and to develop a Li deposition system to meet high volume manufacturing (HVM) requirements from TRL 4 to TRL 8—support DOE's goals.

Reviewer 2:

The reviewer observed that this project is very relevant to DOE's goal to achieve high energy density Li-ion cells for long-range, long cycle life EV application.

Reviewer 3:

The reviewer noted that this project supports the overall DOE objectives by developing a key manufacturing capability for high-energy lithium-ion batteries.

Reviewer 4:

The reviewer agreed that the project supports the overall DOE objectives.

Reviewer 5:

The reviewer said that yes, Li metal and SiO_x-based anodes are potential high energy alternatives to graphite and, if challenges associated with their reversibility are solved, would result in high energy density batteries, in accord with DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted that the funding level is appropriate for the planned work.

Reviewer 2:

The reviewer remarked that the resources are sufficient to achieve the milestones.

Reviewer 3:

The reviewer expressed that the diagnosis part of the project would be strengthened by including a university partner.

Reviewer 4:

The reviewer indicated that for the current progress the funding seems to be excessive, however the reviewer assumed that a lot of the costs are in the later stage of the project associated with machine costs.

Reviewer 5:

The reviewer noted that the resources seem sufficient, although perhaps a bit on the high side ($12 million from DOE over 3 years), for this project.

Presentation Number: bat496
Presentation Title: Silicon Consortium Project: Advanced Characterization of Silicon Electrodes
Principal Investigator: Robert Kostecki (Lawrence Berkeley National Laboratory)

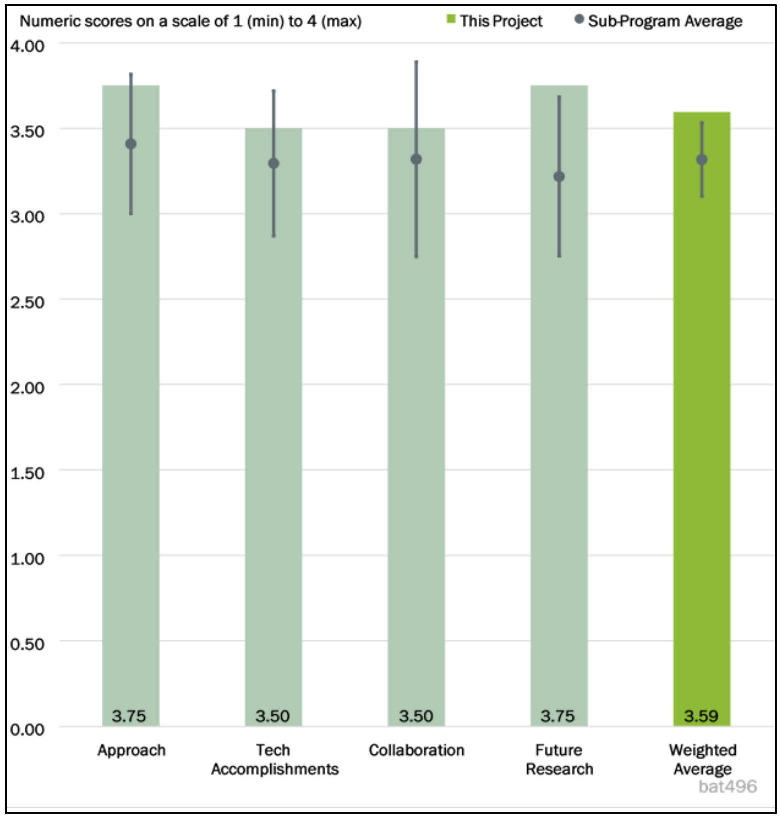


Figure 2-52 - Presentation Number: bat496 Presentation Title: Silicon Consortium Project: Advanced Characterization of Silicon Electrodes Principal Investigator: Robert Kostecki (Lawrence Berkeley National Laboratory)

Presenter

Robert Kostecki, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer noted that the approach to understand SEI on Si surface is outstanding. The reviewer acknowledged that the techniques and the approach to separate and study the material is relevant to meet the objectives of the project.

Reviewer 2:

The reviewer stated that this is highly focused work utilizing advanced diagnostic tools to characterize the Si interface.

Reviewer 3:

The reviewer mentioned that SEI is the most critical part for silicon-based anode to have acceptable cycling and calendar life.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer reported excellent achievements on SEI analysis with advanced characterization techniques.

Reviewer 2:

The reviewer stated that the results presented are very rich and illuminating, and that the project team did a nice job. The reviewer added that the EDS+STEM data beautifully depict how the Si particles break down in course of cycling, which is also nicely supported by the microcalorimetry data. The reviewer also applauded the results from synchrotron xrd and neutron spectroscopy data, along with the SEI composition and structure data. The reviewer was not sure the Zintl phase data are significant enough to be pursued further.

Reviewer 3:

The reviewer mentioned that there are some outstanding results that provide greater understanding of the problem facing Si anode, but that there is still more work needed in identifying the mitigation plans to overcome these challenges.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer reported outstanding collaboration and coordination across all the project teams.

Reviewer 2:

The reviewer noted that extensive collaboration with the other teams is reflected in the data/activities.

Reviewer 3:

The reviewer remarked that the project team is very strong, but that it is mainly composed of national laboratories. The reviewer recommended that since Si is also a hot topic for industry, it could be better to have some battery manufacturers on the team.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer stated that the diagnostic tools at LBNL are always very information-rich and insightful, and it is expected that the work proposed will help gain further insights in the Si/SEI properties. The reviewer is looking forward to the key results in relation to guidance based on the data for Si electrode or electrolyte design that will considerably prolong the durability of this Si anode.

Reviewer 2:

The reviewer indicated that the proposed future plan is appropriate and sufficient.

Reviewer 3:

The reviewer observed that there is lot more work needed to complete the project, but that the approach used to meet the goals is relevant and achievable.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that a full characterization of the Si SEI is essential to develop a robust Si electrode for the next generation Li ion battery.

Reviewer 2:

The reviewer noted that silicon-based anode is a very important candidate to improve lithium-ion battery energy density, which is aligned with DOE objectives. The reviewer added that to develop a good silicon anode, the most challenging task is to find a way to stabilize SEI on Si surface. The reviewer remarked that effective and advanced SEI characterizations will provide scientific guides for electrolyte screening and silicon electrode surface modification.

Reviewer 3:

The reviewer highlighted the importance to further understand how to stabilize the Si surface to make it a useful anode material to gain energy density and DCFC.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer stated that the project is being sufficiently funded.

Reviewer 2:

The reviewer observed that it is sufficient and milestones have been achieved.

Reviewer 3:

The reviewer expressed that the resources are sufficient to meet the program objectives.

Presentation Number: bat497
Presentation Title: Silicon Consortium Project: Electrochemistry of Silicon Electrodes
Principal Investigator: Christopher Johnson (Argonne National Laboratory)

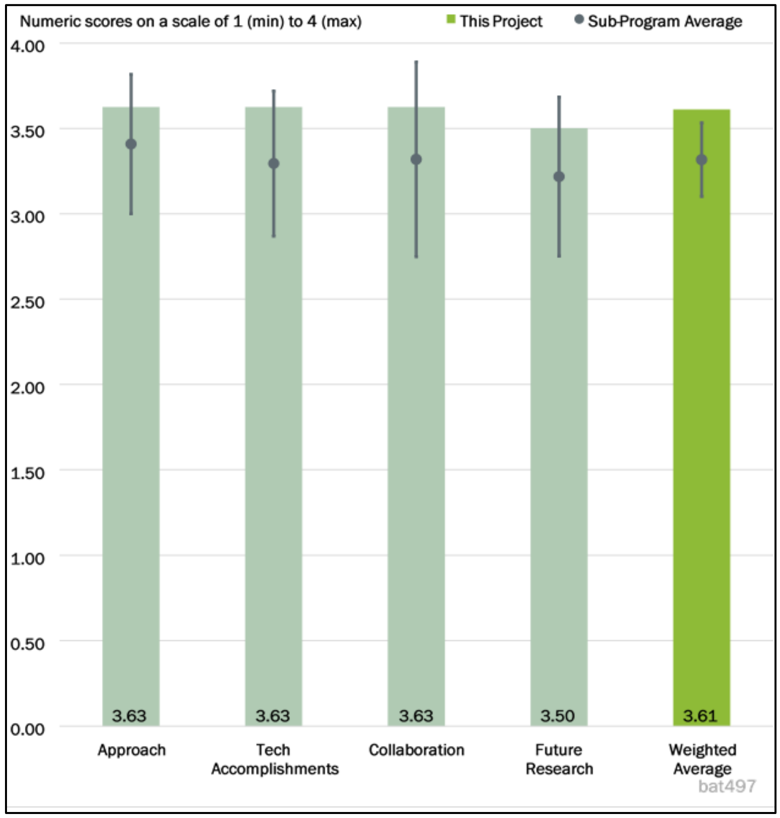


Figure 2-53 - Presentation Number: bat497 Presentation Title: Silicon Consortium Project: Electrochemistry of Silicon Electrodes Principal Investigator: Christopher Johnson (ANL)

Presenter

Christopher Johnson, ANL

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer noted that the project is carefully thought-out and well-planned, involving a good mix of experimental and modeling work.

Reviewer 2:

The reviewer expressed that a stable SEI is very critical to enable high-capacity Si containing anode in LIBs. The reviewer said that however, the understanding of SEI on Si is very limited, and that this approach is in the right direction to have better understanding of Si SEI.

Reviewer 3:

The reviewer remarked that an accelerated method to study calendar aging is very important, specifically for Si anodes. The reviewer added that the approach is relevant to the objectives of the project and is well designed.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer stated that calendar life work using the Vhold technique is a nice protocol developed. The reviewer added that while the principle is well-known, the additional thoughts that went into it to base the work on stable values is appreciated. The reviewer mentioned that the work is world-class and the results are quite insightful. The reviewer asked why one cannot use Jeff Dahn's equipment for the same purpose.

Reviewer 2:

The reviewer observed that the techniques used to evaluate SEI reactivity and calendar life are sound. The reviewer commented that the anode composition, however, is far off from a real anode in LIBs, as it includes too much carbon black and binders, which may limit the value of the work to practical applications.

Reviewer 3:

The reviewer noted that DOE used to study calendar aging, and its correlation to the model is an excellent accomplishment. The reviewer expressed that however, there still is a lot more work that needs to be done to validate the relationship to make the model more useful.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer remarked that there is outstanding collaboration and coordination across all project teams.

Reviewer 2:

The reviewer noted that there is complementary collaborative work as reflected by the modeling data where the modeling expertise came from one lab and the data from this lab.

Reviewer 3:

The reviewer observed that the team is excellent and diversified, and suggested working with industrial partners for practical application.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer stated that a number of important studies have been proposed that will aid in better understanding and advancing the Si anode technology such as modeling of calendar life, and electrode parameters determination to enable modeling work.

Reviewer 2:

The reviewer observed that the plan is sound.

Reviewer 3:

The reviewer indicated that the planned future work will be enough to meet the program objectives, but that there is still more that needs to be done to make the results more useful and relevant.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer said that since Si anode does have the potential to significantly improve the next generation Li ion batteries, this project is very relevant to support DOE objectives.

Reviewer 2:

The reviewer agreed that Si anode is a great candidate for high energy (HE) LIBs, and that SEI study is very critical to enable Si-based anode for HE LIBs.

Reviewer 3:

The reviewer stated that understanding how calendar life affects Si anodes is the most critical problem to solve to make these anodes more useful.

Question 6: ***Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?***

Reviewer 1:

The reviewer remarked that this is a handsomely funded project.

Reviewer 2:

The reviewer indicated that the resources are sufficient to meet program objectives.

Reviewer 3:

The reviewer noted that the team has sufficient personnel and tooling to execute the plan, and that an industrial partner will be a plus.

Presentation Number: bat498
Presentation Title: Silicon Consortium Project: Next-Gen Materials for Silicon Anodes
Principal Investigator: Nathan Neale (National Renewable Energy Laboratory)

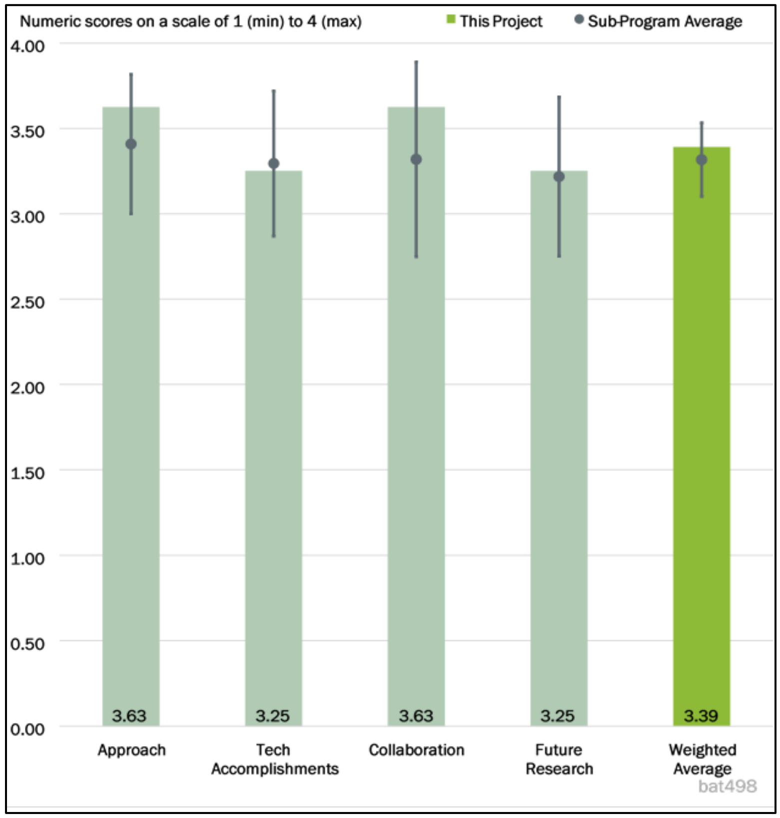


Figure 2-54 - Presentation Number: bat498 Presentation Title: Silicon Consortium Project: Next-Gen Materials for Silicon Anodes Principal Investigator: Nathan Neale (National Renewable Energy Laboratory)

Presenter

Nathan Neale, National Renewable Energy Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer noted that surface modification is a reasonable approach to help build a stable SEI on Si anode surface.

Reviewer 2:

The reviewer observed that while the stated approaches of material and electrolyte composition changes have been practiced quite considerably in these projects, one needs to pursue them further due to the lack of any other out-of-the-box option as of yet.

Reviewer 3:

The reviewer expressed that the approach to study materials that can be used to mitigate issues related to SEI formed on Si is very relevant in making this material useful for battery application. The reviewer added that Si anode stability is an issue that needs more research to understand, but that in parallel, approaches like these are needed to find an alternate solution to the Si stability problem.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer indicated that there is a good number of different approaches being made to improve the stability of Si during cycling. The reviewer commented that understanding why these material composites enable Si stability will be a remarkable accomplishment.

Reviewer 2:

The reviewer stated that the approaches have been regularly used in the past and the results shown here do not indicate as of yet that the team is bringing about a significant impact vis a vis previous results. The reviewer hoped to see considerable improvements to the current results since the project is in its very early stages. The reviewer indicated that the Zintl phase data are not that extraordinary but the Si-titanium (Ti) alloy cyclic voltammetry (CV) data seem interesting. The reviewer also questioned if production using a laser-quenching is a practical process. The reviewer added that some results are difficult to compare. The reviewer explained that the Osaka data, which appear promising at 88% after 700 cycles, were collected at C/10 but those with PECVD B:Si were collected at C/3 and still delivered 500 cycles to 90% capacity retention. The reviewer noted that only these two sets of data seem to stand out.

Reviewer 3:

The reviewer mentioned that the performance looks promising, but that there is too much carbon black and binder in the anode, which is far off from practical applications, which normally have 2-4% binder and less than 2% carbon blacks. The reviewer added that it seems the silicon anode is prelithiated in half cells first and then assembled with a cathode to form full cells. The reviewer highlighted that it is well-known that prelithiation will help compensate initial lithium loss, and that it will be better to use a practical prelithiation method which has potential to be adopted by industry. The reviewer inquired about the first cycle efficiency without prelithiation.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer noted that this is a consortium with outstanding team members with strong interactions among them.

Reviewer 2:

The reviewer remarked that this is an excellent and diversified team.

Reviewer 3:

The reviewer stated that there is outstanding collaboration and coordination across all project members.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer noted that the plan is sound, but that a formulation close to practical application will be preferred.

Reviewer 2:

The reviewer observed that there is lot more that needs to be done to understand how the material interactions affect cycle and calendar life. The reviewer suggested that more research is needed to meet the program objectives, and that cost to benefit analysis is needed to check if these improvements are relevant.

Reviewer 3:

The reviewer commented that aside from the SiTi anode, the rest are well-practiced approaches and it is hard to visualize whether there will be nothing more than low-level incremental improvements to the results that will be attractive from practical application point of view. The reviewer expressed that there is hope that the team will be creative with its selection and make an impact on the program.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer stated that this project is highly relevant in order to develop next generation high energy/low-cost Li ion batteries.

Reviewer 2:

The reviewer commented that silicon materials with surface modification which can facilitate stable SEI formation is critical to support the development of HE LIBs.

Reviewer 3:

The reviewer highlighted the importance of studying alternative methods to mitigate the problems associated with Si stability.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted that the funding level seems appropriate to support this project.

Reviewer 2:

The reviewer commented that the resources are sufficient to execute the plan.

Reviewer 3:

The reviewer remarked that the resources are sufficient to meet the program objectives.

Presentation Number: bat499
Presentation Title: Silicon Consortium Project: Mechanical Properties of Silicon Anodes
Principal Investigator: Katherine Harrison (Sandia National Laboratories)

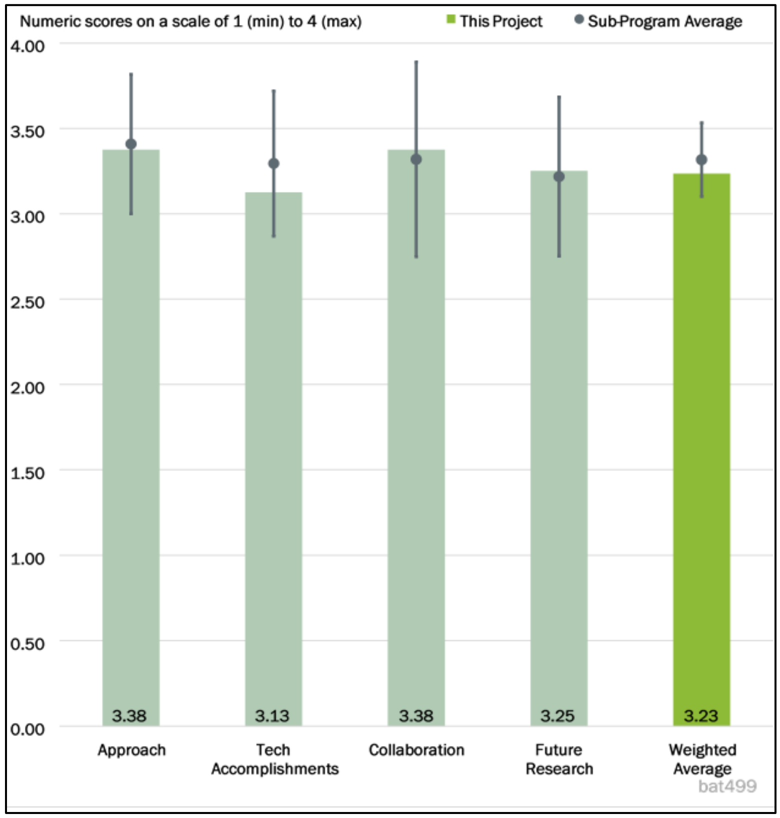


Figure 2-55 - Presentation Number: bat499 Presentation Title: Silicon Consortium Project: Mechanical Properties of Silicon Anodes Principal Investigator: Katherine Harrison (Sandia National Laboratories)

Presenter

Katherine Harrison, Sandia National Laboratories

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer stated that the proposed approaches cover a variety of techniques as listed.

Reviewer 2:

The reviewer mentioned that a stable SEI is critical for the application of silicon-based anode in HE LIBs. The reviewer said that this approach is very helpful to understand how SEI fails on Si anode and thus very beneficial to high-capacity anode development. The reviewer added that the experiment design is executable and sound.

Reviewer 3:

The reviewer observed that the approach to study Si anode mechanical stability is outstanding. The reviewer explained that it is very difficult to differentiate the actual change in thickness from noise from the instrument in this scale, but that the approach using multiple methods to measure the same thing and correlating the results is well designed.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer noted that the project has just started and first data from Moire interferometry show it to be unsuitable due to inaccuracy, but that hopefully scanning microscopy will yield better results.

Reviewer 2:

The reviewer expressed that it has been an excellent effort in understanding which techniques work and which are too noisy to get any good information. The reviewer added that there is still lot of effort needed to understand the relationship between the results from different techniques, and that the go/no-go points need to be well established.

Reviewer 3:

The reviewer indicated that there are very limited results and it is hard to judge.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer remarked that it is a very strong consortium, and that the team will leverage other's expertise effectively.

Reviewer 2:

The reviewer applauded the excellent and diversified team.

Reviewer 3:

The reviewer noted that there is outstanding collaboration and coordination across all project members.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer indicated that the plan is sound, and that the work will help understand how mechanical properties and mechanical manipulation impact life of silicon anodes. The reviewer added that it may provide good guidance for further Si materials surface modification for better stability.

Reviewer 2:

The reviewer noted that there needs to be well defined go/no-go points in the future work to better steer the project to meet its original objectives.

Reviewer 3:

The reviewer expressed that, as mentioned above, several mechanical and electrochemical approaches have been proposed to carry out the mechanical characterization of the SEI, and it remains to be seen how effective they will be. The reviewer suggested that it might be useful to talk to the Xerox PARC team who investigated mechanical strain properties using fiber optics/Bragg.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer remarked that better understanding of the mechanical behavior of the Si SEI layer is useful to design the next generation Li ion batteries.

Reviewer 2:

The reviewer said that yes, the project supports the development of high-capacity anode for HE LIBs.

Reviewer 3:

The reviewer remarked that understanding the mechanism of mechanical failure in Si anodes will help make the material more applicable to automotive applications that require long calendar life.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer indicated that the funding level seems sufficient to provide good support for the project.

Reviewer 2:

The reviewer mentioned that the resources are sufficient to achieve the planned tasks.

Reviewer 3:

The reviewer expressed that the team has sufficient resources to complete the project.

Presentation Number: bat500
Presentation Title: Silicon Consortium Project: Science of Manufacturing for Silicon Anodes
Principal Investigator: Gabe Veith (Oak Ridge National Laboratory)

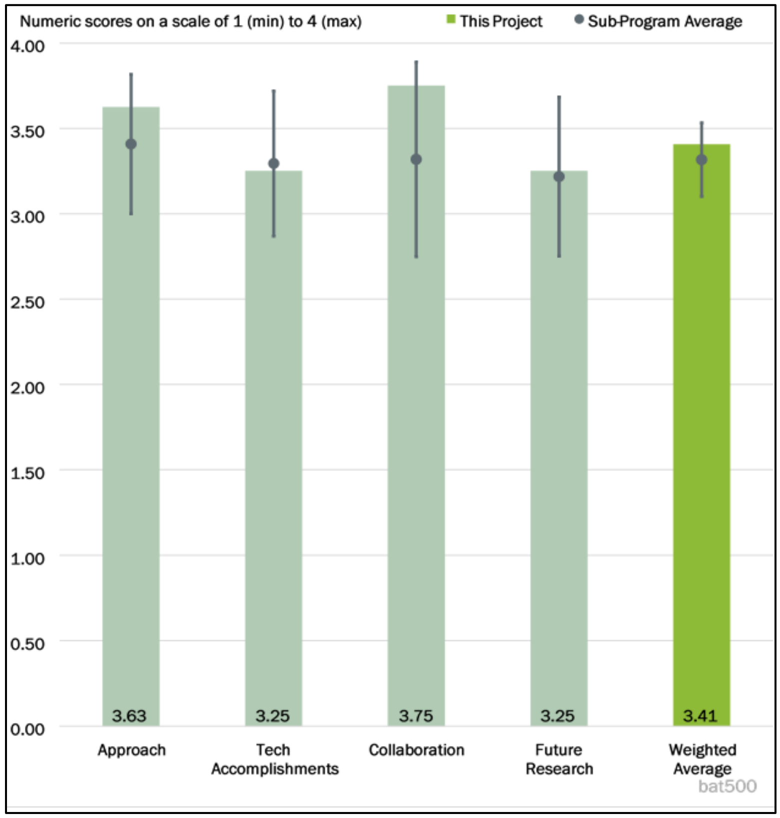


Figure 2-56 - Presentation Number: bat500 Presentation Title: Silicon Consortium Project: Science of Manufacturing for Silicon Anodes Principal Investigator: Gabe Veith (Oak Ridge National Laboratory)

Presenter

Gabe Veith, Oak Ridge National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer remarked that there are several attractive approaches such as coating and pre-lithiation that have been investigated to stabilize the Si anode materials.

Reviewer 2:

The reviewer expressed that in general, carbon coated Si materials as well as prelithiation would extend cycling life of LIBs with silicon anode, which can increase energy density of EV batteries for longer driving range.

Reviewer 3:

The reviewer noted that fabricating carbon coated Si and Si prelithiation are two of the best approaches to mitigate Si anode instability during cycling. The reviewer highlighted the importance of understanding how manufacturing techniques can affect the performance of these techniques.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer observed that while electrochemical pre-lithiation is a well-established process now, the thermal evaporation method seems interesting based on the initial results. The reviewer noted that it is not clear how efficient this process is for scaling up, for uniformity, and from a cost and mass-production point of view.

Reviewer 2:

The reviewer remarked that the project made good progress on carbon coated Si preparation. The reviewer expressed that there is no data, however, to support the claim of "Achieved 1000 cycles with greater than 80% capacity retention with new cell chemistries". The reviewer added that the specific capacity for silicon anode on Slide 4 is too low, below 150mAh/g, less than half that of normal graphite anode. The reviewer said that the prelithiation protocol might be good for a concept proof in the lab, but that it is not practical.

Reviewer 3:

The reviewer noted that there is good progress in demonstrating which manufacturing conditions improve performance, but that there is still more work needed in understanding the failure mode for thick Si anode coatings. The reviewer stated that the mitigation will have to involve understanding how the properties of all the material interact when thick electrodes are made, and that is going to take a lot of effort.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer expressed that the collaboration with other teams was reflected in the work to understand material and processing issues for Si anodes, neutron scattering and coating method development.

Reviewer 2:

The reviewer noted an excellent and very diversified team.

Reviewer 3:

The reviewer applauded the outstanding collaboration and coordination across all the team members.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer stated that the future plan sounds reasonable, and that the key to make silicon anode stable is SEI formation and gassing reduction during cycling and storage. The reviewer recommended incorporating these two into the future plan.

Reviewer 2:

The reviewer observed that future work to further explore the thermal evaporation method seems interesting. The reviewer added that the other work proposed, such as studies with reduced binder or other carbon coatings (not specified though), seems a little generic with unclear impact.

Reviewer 3:

The reviewer said that there is a lot more future work needed to understand the mechanism involved in making thick Si anode work as expected. The reviewer noted that the project needs to refocus efforts on identifying and optimizing specific conditions that give the most benefit towards achieving the program objectives.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer remarked that manufacturing high quality Si anodes is very important to develop next generation Li ion batteries.

Reviewer 2:

The reviewer observed that silicon-based anode materials are a critical candidate for high energy EV battery development.

Reviewer 3:

The reviewer said that it is extremely relevant to understand how manufacturing conditions and material interactions affect Si anode performance. The reviewer added that optimizing these is the clear path to meeting the objective of making a viable Si anode that is useful for the automotive industry.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer commented that the funding for this part of the work seems appropriate.

Reviewer 2:

The reviewer noted that the resources are sufficient to achieve milestones, and that it may be a plus to have an industrial partner to have better understanding and a point of view for practical applications.

Reviewer 3:

The reviewer remarked that the program has sufficient resources to meet the objective set at the start.

Presentation Number: bat501
Presentation Title: Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Silicon Anode
Principal Investigator: Kristin Persson (Lawrence Berkeley National Laboratory)

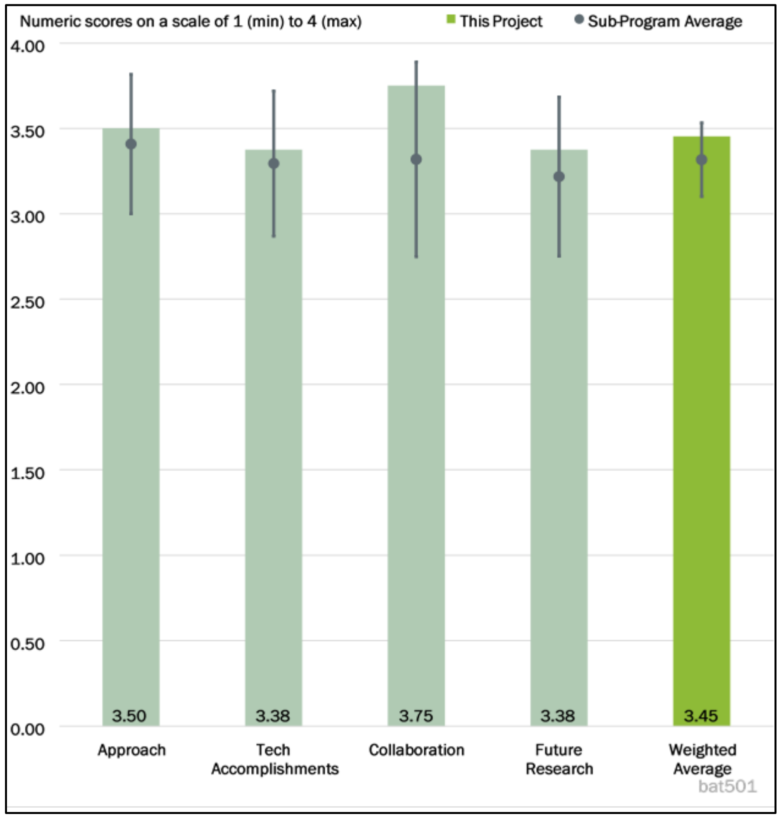


Figure 2-57 - Presentation Number: bat501 Presentation Title: Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Silicon Anode Principal Investigator: Kristin Persson (Lawrence Berkeley National Laboratory)

Presenter

Kristin Persson, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 25% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer indicated that the approach in this study was highly organized, involving leading-edge computational studies leveraging the most sophisticated modeling tools out there.

Reviewer 2:

The reviewer expressed that it is great to find a possible reaction path for the formation of known components in SEI. The reviewer stated that it will be excellent to utilize the findings to predict products from new electrolyte designs.

Reviewer 3:

The reviewer remarked that SEI on Si anode is one of the most complex systems in the battery industry to understand. The reviewer reported that there are just too many variables to properly understand the optimized conditions that enable the best performance from Si anode. The reviewer commented that the approach to model SEI so these variables can be narrowed down is well designed.

Question 2: ***Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.***

Reviewer 1:

The reviewer stated that the results are remarkable. The reviewer explained that it can be exemplified by the results that lead to the formation of LEDC, involving 6,000 species and 4,500,000 reactions. The reviewer asked how one defines "expected" and "novel," and of the novel, how one distinguishes whether this is indeed a plausible route. The reviewer asked if the model imposes both thermodynamic and kinetic pass/fail criteria before moving on to the next steps.

Reviewer 2:

The reviewer observed that progress has been made to find the possible reaction path for SEI some components.

Reviewer 3:

The reviewer indicated that there has been good progress made in developing the model to train it to select relevant variables, but that there is still a lot more that needs to be done to further improve probability and correlate it with physical confirmation.

Question 3: ***Collaboration and Coordination Across Project Team.***

Reviewer 1:

The reviewer reported that multiple studies within the project involved close collaboration among the consortium members.

Reviewer 2:

The reviewer noted an excellent and very diversified team.

Reviewer 3:

The reviewer stated that there is outstanding collaboration and coordination across all project team members.

Question 4: ***Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.***

Reviewer 1:

The reviewer stated that the work proposed is a ground-breaking from a battery researcher's point of view, and helps to really understand the evolution of these mechanisms via the modeling work. The reviewer asked how one can know how reliable these modeling results are. The reviewer asked if there is any surrogate, hopefully less complex system, that can be modeled to validate such work.

Reviewer 2:

The reviewer said that the project is to use modeling support silicon and development, and that it may be more beneficial to find how SEI forms differently on Si compared with graphite.

Reviewer 3:

The reviewer indicated that there is lot more that needs to be done to make the model work with high confidence. The reviewer commented that the effort needed to overcome the challenges seem to be too great, and that there needs to be a refocus on work plan to meet the final program objectives.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer expressed that fundamental understanding of the SEI characteristics derived via modeling is of utmost significance to develop Si-based next generation Li ion batteries.

Reviewer 2:

The reviewer said that yes, SEI is critical for the development of high energy LIBs with Si anode, which has high potential for EV batteries for longer driving range.

Reviewer 3:

The reviewer mentioned that the model activity is very important to find answers related to Si anode stability. The reviewer explained that the model should be used to guide the experiments to understand how the various materials interact to improve Si anode stability.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer commented that this is a well-funded project.

Reviewer 2:

The reviewer noted that the resources are sufficient to achieve the milestones.

Reviewer 3:

The reviewer remarked that the time and effort needed to achieve the objective are not sufficient. The reviewer explained that this effort will need additional resources to run the various conditions needed, and that the program objective needs a refocus to achievable results.

Presentation Number: bat502
Presentation Title: Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Si Anode (Si-HPC)
Principal Investigator: Andrew Colclasure (National Renewable Energy Laboratory)

Presenter

Andrew Colclasure, National Renewable Energy Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 25% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

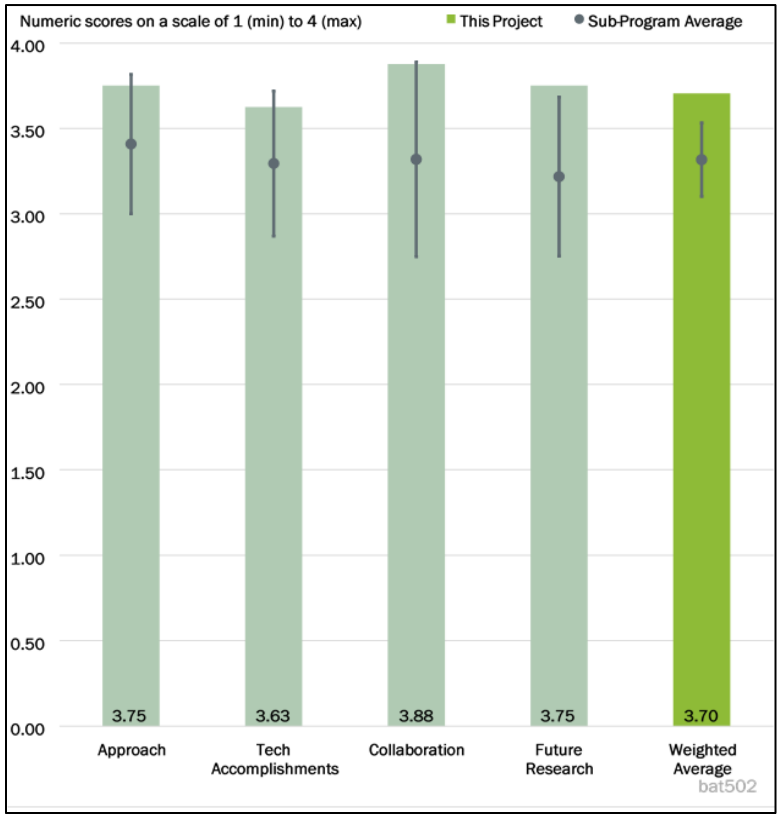


Figure 2-58 - Presentation Number: bat502 Presentation Title: (PI to provide a new title) Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Si Anode (Si-HPC) Principal Investigator: Andrew Colclasure (National Renewable Energy Laboratory)

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer said the approach to understanding Si anode stability in an electrolyte is outstanding. The models will help narrow down the variables by removing highly improbable conditions.

Reviewer 2:

The work was very well-organized making use of the atomistic models developed at LBNL and ORNL.

Reviewer 3:

The reviewer remarked that it is great to find a possible reaction path for the formation of known components in SEI. It will be excellent to utilize the findings to predict products from new electrolyte designs.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer said this is a very comprehensive study aimed at understanding the SEI characteristics at the Si surface leveraging atomistic modeling carried out at LBNL and ORNL. Results of this complex modeling seems to confirm what we experimentally know, i.e., the expected effects of such parameters as voltage, resistance, or expansion/contraction.

At the end of the day though, one would love to use these results to design, develop, or predict the behavior of the corresponding system. While the data obtained thus far are insightful, the reviewer asked whether that goal can be reached with these studies.

Reviewer 2:

The reviewer commented that good progress has been made to predict the thickness growth of SEI film and the dependence on voltage. Have efforts been made to validate these findings with experimental data?

Reviewer 3:

The objectives set at the start of the year has been achieved, but the reviewer indicated that there is still lot more to be done to meet overall project objectives.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said there is outstanding collaboration and coordination across all the project members.

Reviewer 2:

An excellent and very diversified team was observed by this reviewer.

Reviewer 3:

The reviewer remarked that this work had active collaboration with the other modeling teams of LBNL and ORNL as evidenced by the data shown.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer asserted that the plan is sound, especially inclusion of "Implement Si particle chemo mechanical influences on SEI performance."

Reviewer 2:

The reviewer noted a list of important activities that will advance the understanding of Si SEI layer has been proposed including incorporation of additional species, experimental validation of the developed mechanism (especially the current and species concentration), and mechanical considerations of the SEI layer. Despite the very comprehensive nature of these studies, they are based on a whole slew of assumptions. The reviewer remarked that it would be good to show some analysis that reflects the fidelity of these results as a function of those assumptions.

Reviewer 3:

This reviewer indicated that there is a lot more to be done to achieve project objectives and suggested that future work may need to be refocused to achieve the final objective in the provided time.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer affirmed that, yes, and noted that SEI is critical for the development of high-energy LIBs with a Si anode, which is a highly potential candidate for EV batteries for longer driving range.

Reviewer 2:

The reviewer remarked that the basic understanding and modeling of the Si interface is important for developing next-generation LIBs.

Reviewer 3:

The reviewer said that it is very relevant to reduce the variables in understanding the stability of a Si anode in the electrolyte.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer remarked that the funding level is appropriate.

Reviewer 2:

The reviewer said that resources are sufficient to achieve milestones.

Reviewer 3:

The reviewer commented that the project would need more time and more funds to complete the stated objective, or there needs to be a refocus of the objectives to complete on time.

Presentation Number: bat503
Presentation Title: Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Silicone Anode
Principal Investigator: Jean-Luc Fattebert (Oak Ridge National Laboratory)

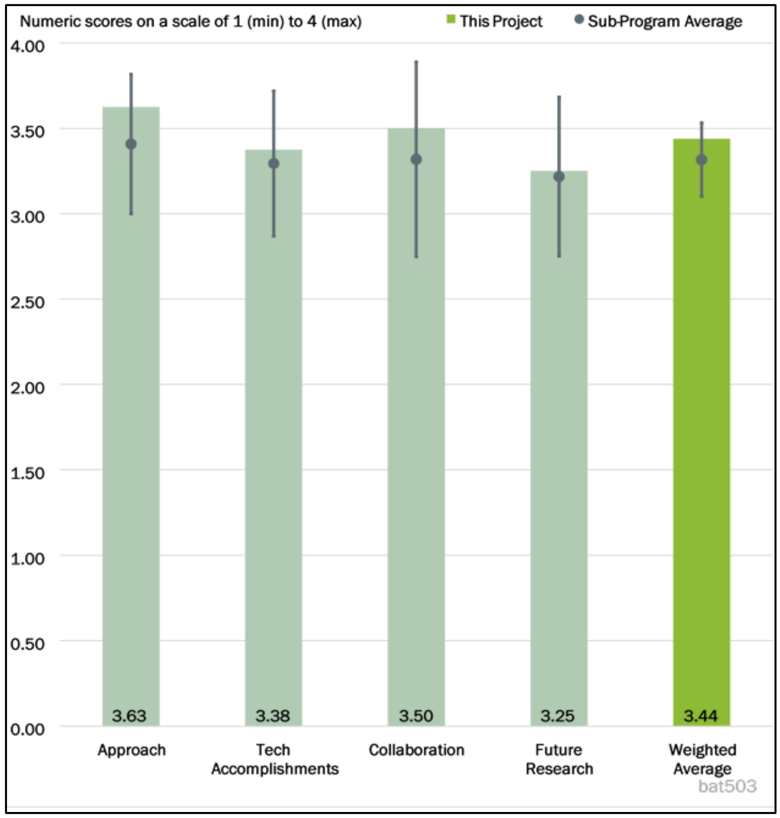


Figure 2-59 - Presentation Number: bat503 Presentation Title: Integrated Modeling and Machine Learning of Solid-Electrolyte Interface Reactions of the Silicone Anode Principal Investigator: Jean-Luc Fattebert (Oak Ridge National Laboratory)

Presenter

Jean-Luc Fattebert, Oak Ridge National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 25% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

For this reviewer, it is great to find possible reaction path for the formation of known components in SEI. It will be excellent to utilize the findings to predict products from new electrolyte designs.

Reviewer 2:

The reviewer remarked that this is very advanced work to simulate the generation of species at the SEI using molecular dynamics techniques.

Reviewer 3:

The reviewer remarked it is an outstanding effort to model SEI on a Si anode. There are just too many variables to effectively understand how the interaction between the Si anode and an electrolyte happens.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer said that while it is understood that a number of assumptions were made (which may or may not be fully correct) for this modeling work, it is highly gratifying and instructive to see that these studies led to a good agreement with what people macroscopically had found out.

Reviewer 2:

Progress has been made to show formation of inorganic and organic products in SEI, according to this reviewer.

Reviewer 3:

The reviewer noted that there is some good development in the model that shows how the initial interaction of the electrolyte occurs with a Si anode, but there is still much more that needs to be done to understand Si stability in relevant real-world conditions.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted an excellent and very diversified team.

Reviewer 2:

The reviewer commented that there is outstanding collaboration and coordination across all project team members.

Reviewer 3:

The reviewer remarked that it can be easily expected that the PI had a lot of collaboration with the LBNL and NREL teams, leading centers for such modeling work.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer pointed out that given the fact a framework has been developed, it will be interesting to see, as the author proposes, how other parameters–additives, anode surface, binder, temperature, or even types ([Li] metal), etc.—affect the SEI characteristics. It would, however, be important to carry out sensitivity analysis on the various assumptions made during the modeling. This would give researchers some level of confidence in the data.

Reviewer 2:

The reviewer commented that the project is to use modeling to support Si development. It may be more beneficial to find how SEI forms differently on Si compared with graphite. It may be more meaningful to focus on a larger time scale since the unit for the life of the LIB is a year, not a second.

Reviewer 3:

The reviewer remarked there is lot more work to be done to meet final project objectives. Future work needs to be refocused to meet project objectives.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer commented fundamental understanding of the SEI growth mechanism on the Si electrode is of utmost importance to an improved anode and consequently an improved, next-generation LIB.

Reviewer 2:

The reviewer affirmed that, yes, and explained that SEI is critical for the development of high-energy LIBs with a Si anode, which is a highly potential candidate for EV batteries for longer driving range.

Reviewer 3:

The reviewer pointed out that it is very relevant to understand the interactions between Si anode and electrolyte.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The funding level seemed appropriate to this reviewer.

Reviewer 2:

The reviewer remarked that resources are sufficient to achieve milestones.

Reviewer 3:

The reviewer commented that there is lot more that needs to be done to meet project objectives. The team needs more resources to meet them in a timely fashion.

Presentation Number: bat504
Presentation Title: 3D Printed, Low Tortuosity Garnet Framework for Beyond 500 Wh/kg Batteries
Principal Investigator: Eric Wachsman (University of Maryland)

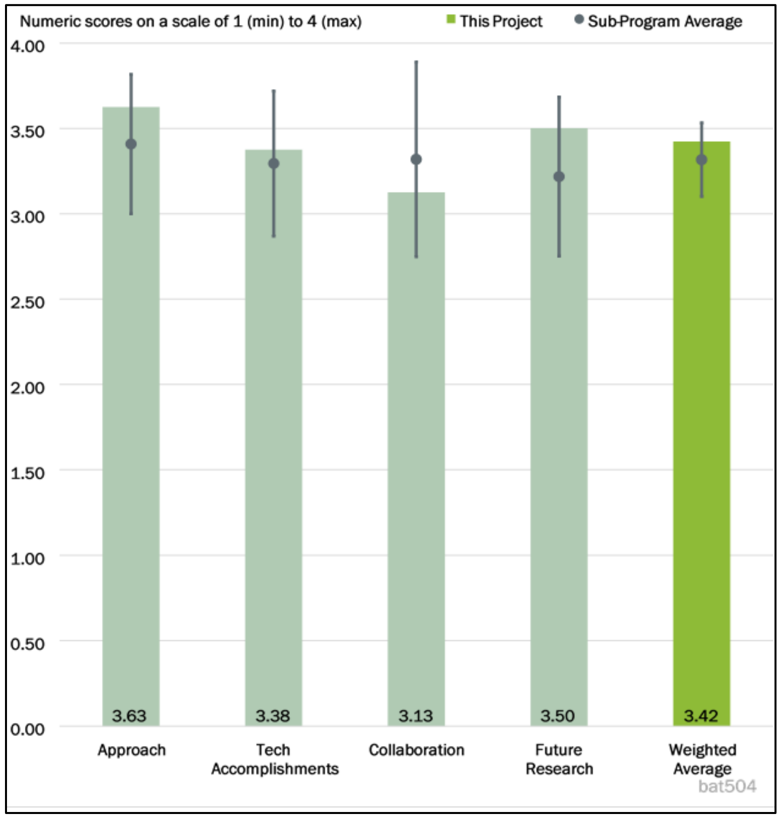


Figure 2-60 - Presentation Number: bat504 Presentation Title: 3D Printed, Low Tortuosity Garnet Framework for Beyond 500 Wh/kg Batteries Principal Investigator: Eric Wachsman (University of Maryland)

Presenter

Eric Wachsman, University of Maryland

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer remarked that the low tortuosity, high porosity electrode fabrication approach is compelling.

Reviewer 2:

The reviewer detailed how the approach of this project, as performed by Wachsman, Hu, and co-workers, aims to form 3-D printed, low tortuosity frameworks of Li garnets for batteries with gravimetric energy densities beyond 500 Wh/kg. The main technical barriers addressed are (1) improvement of the electrode/electrolyte interfaces by precisely tuning the interfacial surface area through 3-D printing ceramics and (2) structure-property relationships of how different ceramic architectures affect the total energy density, depth of discharge, and the C-rate. These barriers are indeed important, and the approach is quite novel among ceramic processing, especially with multi-cation ceramics like Li garnets. The reviewer observed that although this project was delayed by COVID-19, the team did an adequate job performing the experiments, as outlined in their approach. Overall, the team has implemented an effective approach to overcome these barriers.

Reviewer 3:

The reviewer commented that the team developed 3-D printing techniques to build architected solid-state electrolytes (SSE) to enhance the contact with electrode materials. The approach has the potential to decrease interfacial resistance and enhance mechanical robustness and therefore increase the energy density and possibly rate performance. The integration of modeling work helps guide the experimental designs of the printed architecture. The reviewer said the project is well designed.

Reviewer 4:

The reviewer pointed out that the 3-D printed SSE will enable thicker electrodes with more interfacial surface areas for higher energy density.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer said the project "3D Printed, Low Tortuosity Garnet Framework for Beyond 500 Wh/kg Batteries" reports a number of important accomplishments. This project led to models of cathode structures and their relation to electrochemical properties; enabled novel ceramic processing techniques such as 3-D printing to achieve ceramic architectures that were predicted by the models; optimized 3-D structures; improved cathode-electrolyte interfaces with garnets and sulfur (S)/nickel manganese cobalt oxide (NMC); and led to cells that approach 500 Wh/kg. Overall, the technical accomplishments are effective and contribute to overcoming the barriers for Li garnet SSEs.

Reviewer 2:

The reviewer noted that the project is 80% complete due to pandemic delay. The cell-level optimization and performances are limited (e.g., 300 Wh/kg and 500 Wh/kg for Li-S or Li-NMC). However, the experiments show very promising preliminary results with this 3-D printing approach. The different 3-D structures for Li-NMC and Li-S are well designed.

Reviewer 3:

The reviewer said this year the team conducted simulation work to optimize the 3-D architecture and compared it with experimentally derived structures. The conclusion is finer features with lower tortuosity is preferred, which is intuitively expected. Due to the pandemic, the PI mentioned the progress of the experimental part has been unfortunately delayed, while good progress has been made in the cell performance testing.

Reviewer 4:

The reviewer remarked that, generally, the early data look promising, and it is nice that this SSE can be used with both high-voltage NMC and high-capacity S cathode materials. But clearly interfacial and other impedances are still major issues to be overcome here. The NMC electrochemical data (Slide 11) is with a loading of 1.5 mg/cm^2 and at a rate of 0.05C. Note that the loading is equivalent to about 0.25 mAh/cm^2—a factor of 10 too thin compared to commercial systems.

The reviewer said that the S results on Slide 9 are much different, with a report of 3.2 mAh/cm^2 and current of 20 mA/g which is 7C, which seems to possibly be a misprint. The reviewer noted it is very rare to cycle a solid-state battery (SSB) or a S cell at such a high rate.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer remarked the team appears to have close, appropriate collaborations as well as coordination with other institutions.

Reviewer 2:

Although minimal collaboration was shown, this reviewer indicated that it is not critical because this is a university R&D project.

Reviewer 3:

The reviewer said the team listed one collaborator.

Reviewer 4:

The reviewer noted that the team has one university collaborator.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer commented the proposed research seems to be similar to last year's due to the pandemic delay. As of the project end date, the project is not 100% finished. It is important to finish the rest of the work because it is very interesting and promising.

Reviewer 2:

The reviewer said that there are very aggressive future plans to make cells that deliver 500 Wh/kg and cycle 200 times—it seems highly unlikely, given the current loadings and rates shown here. The reviewer noted that the reported 800 mAh/g of the team's S cathode is impressive, but well below the theoretical capacity.

Reviewer 3:

The reviewer commented the team plans to continue the effort in the remainder of fiscal year FY) 2021. Although the team has shown preliminary cell performance testing results, there is still a big room for improvement. For example, the mass loading of NMC or S is still far from a practical application and the set goal of 300 Wh/kg. How to avoid the use of liquid electrolyte in cell performance testing is still a challenge to be solved.

Reviewer 4:

The reviewer pointed out the project "3D Printed, Low Tortuosity Garnet Framework for Beyond 500 Wh/kg Batteries" has ended (March 31, 2021).

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer said that the project is highly relevant.

Reviewer 2:

The reviewer said the 3-D printing of the low tortuosity garnet framework is a good SSE candidate for both Li-ion and Li-S batteries. In addition, the 3-D printing is a repeatable and scalable process.

Reviewer 3:

The reviewer detailed that this project is relevant to a number of DOE objectives, namely, the objective to develop affordable batteries with increased energy densities (or specific energies) for applications in the EV market. Although this project has overcome some of the technical objectives, there is still more work to do, as cathode/SEI still present numerous issues in different battery systems. While this project achieved greater than 300 Wh/kg batteries, it was noted that more funding will be necessary to try other types of architectures and further scale the production of these architectures. This project addresses many of the DOE goals and also achieves some of the technical objectives of the Battery500 program.

Reviewer 4:

The reviewer said the project is supportive of DOE's objective in clean energy storage and electrification of vehicles, given that SSBs are a much safer and higher-energy-density choice. The project aims to tackle the manufacturing of SSBs that are far from mature. Proper integration techniques that can maximize the benefits from high-capacity metallic Li, high conductivity and safe SSE, and high-capacity cathodes, are urgently needed.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer noted that due to COVID-19, this project was delayed and the team stated that it took a no-cost extension. This reviewer found that cathode-SEIs are incredibly important and deserve special attention from the DOE. This team has the proper equipment and resources to carry out this kind of research, and this team also has a number of active collaborations both internally and externally. These collaborations can help expedite this work if it continues to receive funding from future calls.

Reviewer 2:

The reviewer saw no issues with resources.

Reviewer 3:

The reviewer remarked the team has great resources to finish the project.

Reviewer 4:

The reviewer said the team has the resources to complete the required work. It seems that an extended period might be needed to tackle the technical challenges.

Presentation Number: bat505
Presentation Title: Advanced Electrolyte Supporting 500 Wh/Kg Li-C/NMC Batteries
Principal Investigator: Chunsheng Wang (University of Maryland)

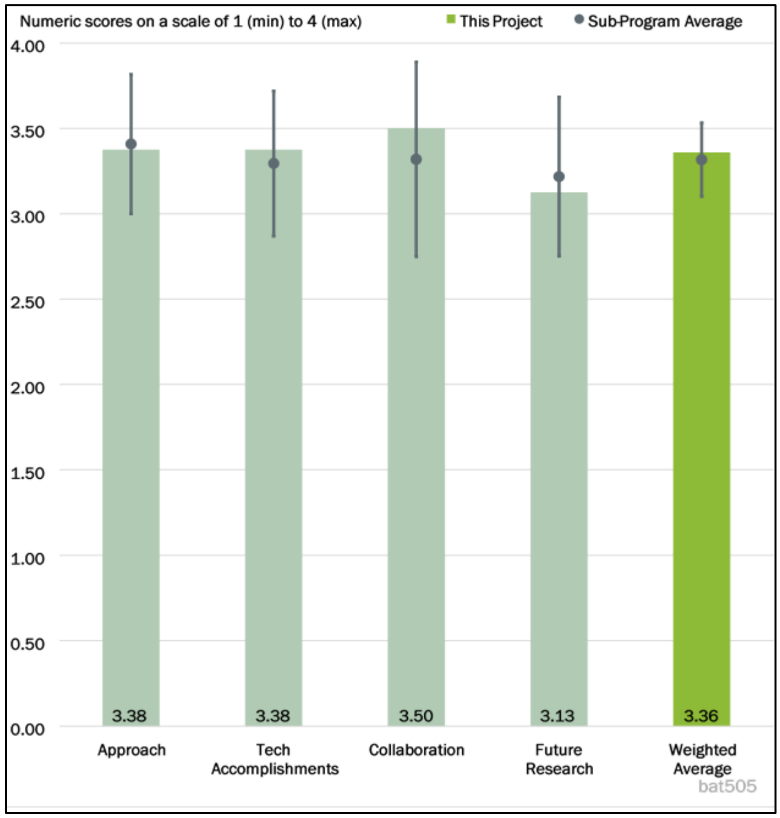


Figure 2-61 - Presentation Number: bat505 Presentation Title: Advanced Electrolyte Supporting 500 Wh/Kg Li-C/NMC Batteries Principal Investigator: Chunsheng Wang (University of Maryland)

Presenter

Chunsheng Wang, University of Maryland

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer said the team wants to use Li-metal in a cell and plans to do this by creating a an SEI that is mostly lithium fluoride (LiF). The team plans to do this through several approaches including a nitrate reinforced carbonate electrolyte, a solvent-free eutectic electrolyte, and a new ionic liquid electrolyte.

Reviewer 2:

The reviewer noted that this project focuses on addressing Li dendrite and interfacial issues in Li batteries, which are important and relevant to DOE's objectives. The proposed approaches of nitrated reinforced carbonate electrolyte, eutectic electrolyte, and ionic liquid electrolyte are scientifically sound and were proved effective to form a LiF-rich SEI Li anode.

The reviewer cited how concerns of using $LiNO_3$ in Li/NMC811 are chemical instability and safety concerns of $LiNO_3$ in high-voltage/energy Li batteries. For eutectic and ionic liquid electrolytes, Li-ion transport properties in the electrolyte and wetting of thick electrodes would be problematic in practically high-energy Li batteries.

Reviewer 3:

The reviewer commented the “Strategy/Approach” is based on two unproven speculations: the “LiF-Li_3N SEI” bonds weakly with Li, allowing it to expand or shrink with Li; and LiF SEI promotes Li diffusion along the LiF-Li interface. The reviewer remarked there is no evidence for either.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer commented that the new electrolytes, e.g., nitrate reinforced carbonate electrolytes, solvent-free eutectic electrolyte, and ionic liquid electrolyte, appear to be highly promising.

Reviewer 2:

The reviewer said the PI and team successfully deployed the proposed approaches in the project. LiF-rich SEI was proved effective in improving Li cycling efficiency and extending cell cycle life. Long cycling at lean electrolyte conditions is still a challenge. This project focuses on the fundamental problems of high-energy Li-NMC cell; however, it seems that the PI put too much effort on the low--voltage materials of sulfurized polyacrylonitrile (S@PAN) and sulfurized porous carbon (S@PC). The reviewer noted that no results were reported on the Li-C anode, which is an important part of this project.

Reviewer 3:

The reviewer remarked that the team made cells with nickel cobalt aluminum oxide (NCA) and NMC 811 as the cathode with Li and a nitrate-based electrolyte and showed good cyclability for 150 cycles and compact Li plating. The team used the same electrolyte in a Li-S cell where PAN was used as the binder in the cathode. The cell cyclability capacity was less than 700 mAh/g for about 90 cycles. The reviewer noted how the team used the solvent-free eutectic electrolyte in a S cell and operated at 80°C, 30°C above the eutectic temperature. Again., the team gets about 700 mAh/g cyclability capacity and measured a CE of the Li of 99.2%. For this ionic liquid, the team again expects an LiF SEI that will suppress dendrite growth; using NCM again, the team gets good cyclability to 120 cycles with regard to CE and shows 85% capacity retention after 120 cycles. In pouch cells, the reviewer indicated that the team achieved 300 cycles, but the cells are just 2 mAh/cm^2. None of the results so far are off the charts although the CE still looks good. The ionic liquid is used in a Li-S cell and the team still just gets 600 mAh/cm^2.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer noted collaborations with experts at U.S. Army Research Laboratory (ARL), Saft America, and BNL seem to be highly effectively.

Reviewer 2:

The reviewer said the team brought in real experts from industry and national laboratories to get critical work and guidance.

Reviewer 3:

The reviewer remarked the PI has close collaborations with ARL, a national laboratory, and the battery industry.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer remarked this project has a clear plan for future work. Efforts on Li-NMC811 should be enhanced to extend the cycle life at both high areal loading and lean electrolyte conditions. Efforts on S@PAN and S@PC may be diluted.

Reviewer 2:

The reviewer recommended that future research should include experimental investigation of the two basic assumptions that (1) the "LiF-Li_3N SEI" bonds weakly with Li allowing it to expand or shrink with Li and (2) LiF SEI promotes Li diffusion along the LiF-Li interface.

Reviewer 3:

The reviewer said that future plans are very specific other than to try to make everything better.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer commented the project is highly relevant to the DOE objectives.

Reviewer 2:

The reviewer said the Li-NMC battery technology has a high potential to realize high energy and long lifespan as a promising next-generation battery technology. This project aligns well with DOE's objectives of vehicle electrification.

Reviewer 3:

The reviewer pointed out that DOE wants to get to 500 Wh/kg, and this can be done with a Li anode. This work provides three ways to get there. There need to be more cycling data to see when or if the dendrites appear.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer said the PI has close collaborations externally and has sufficient resources to perform the proposed research.

Reviewer 2:

The reviewer remarked resources seem sufficient. The researchers need more effort on the S electrode and more cycling data on their NCM and NCA cells to see how well their electrolyte is suppressing dendrites.

Reviewer 3:

The reviewer commented the team has excellent resources.

Presentation Number: bat506
Presentation Title: Composite Cathode Architectures Made by Freeze-Casting for All Solid State Lithium Batteries
Principal Investigator: Marca Doeff (Lawrence Berkeley National Laboratory)

Presenter

Marca Doeff, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 25% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

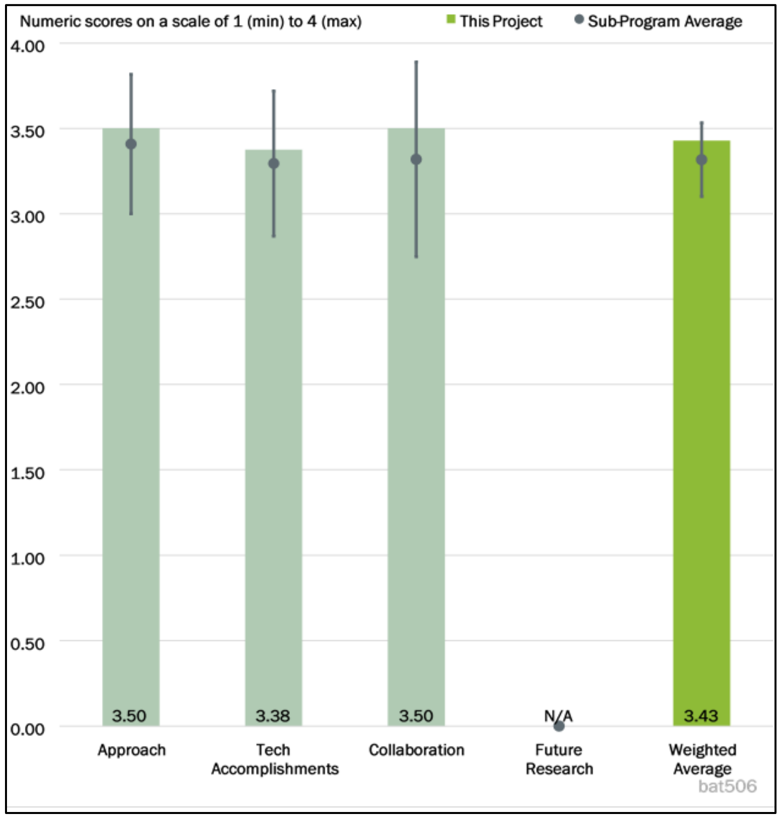


Figure 2-62 - Presentation Number: bat506 Presentation Title: Composite Cathode Architectures Made by Freeze-Casting for All Solid State Lithium Batteries Principal Investigator: Marca Doeff (Lawrence Berkeley National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer found that freeze-tape casting lithium lanthanum zirconium oxide ($Li_7La_3Zr_2O_{12}$, LLZO) then infiltrating with NMC is a nice idea, and could help with reducing interfacial impedance. There are nice diagnostics to discover that LLZO reacts with many carrier solvents versus reactivity between LLZO and succinonitrile (SN).

Reviewer 2:

The reviewer noted that the approach of this project, as performed by Doeff and co-workers, aims to form composite cathode architectures via freeze-tape casting for next-generation all-solid-state batteries. The main technical barriers addressed are (1) energy density and (2) cost of production. While the energy density of the batteries can be calculated by the lab-scale demonstrations of the calls, the cost is somewhat difficult to calculate. Both of these barriers are indeed important, and the reviewer noted that the approach is quite novel among ceramic processing (e.g., freeze-tape casting of dense/porous bi-layers and tri-layers). Although this project was delayed by COVID-19, the team did an adequate job performing the experiments, as outlined in their approach. The team also completed optimization steps to tune the porosity of the LLZO, which allowed better infiltration of the cathodes. Also, the team has addressed the origins of the cathode/LLZO interfacial impedance, which is a major contributor to compromised battery performance. Overall, according to the reviewer, the team has explored a novel approach to forming dense/porous Li garnet architectures, but still require future work to further improve energy density of all-solid-state cells.

Reviewer 3:

The reviewer commented freeze-tape casting can make porous structures with high directionality and thin thickness for use in SSBs. The challenge is that the aligned pores will tilt during the processing, as shown in Slide 7. There is a tradeoff between making the structure thin and making the pores highly aligned.

Reviewer 4:

The reviewer said the project focuses on infilling of cathode materials into a freeze-casted porous/dense bi-layer LLZO film to increase the contact between electrode and electrolyte. If successful, the approach can be scalable and the cell performance can be improved, which addresses the energy density and cost barriers. The project includes fabrication and cell testing only for the 2-year term. It was well designed for the scope and budget. Improving the infilling efficiency seems to be very challenging using the freeze-casted template due to the less controlled porous channels. To make this approach more practical, the reviewer suggested that more efforts might be needed to increase the cathode loading.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer commented the team showed reasonable charging-discharge performance based on the all-solid-state design at room temperature. SN was added to increase the ionic conductivity and enhance the contact and showed beneficial effects in cell performance.

Reviewer 2:

The reviewer said the project “Composite Cathode Architectures Made by Freeze-Casting for All Solid-State Lithium Batteries” reports a number of important accomplishments. This project led to the development of a novel method to make porous/dense bi- and tri-layer Li garnet scaffolds and gained an understanding of the origins of the high impedance at the cathode/SEI. The team optimized freeze tape-cast structures, developed methods to better infiltrate cathodes into porous Li garnets, and came up with methods to better wet the Li-Li garnet interface (e.g., zinc oxide [ZnO]). While these technical accomplishments are all excellent, the energy density of as-assembled cells was quite low with the NMC 811 cathodes. The reviewer posited that further assessment of the NMC/Li garnet interface may provide evidence as to the origin of the interfacial impedance. As noted in the presentation, infiltration is still a major hurdle for this project. While the approach is novel, more attention could be given to this issue. As noted, solvents can possibly degrade LLZO (e.g., rapid H^+/Li^+ transfer between the ceramic and the solvent).

Reviewer 3:

The reviewer said the progress is good, and the filtration of active materials is still the big challenge for the project.

Reviewer 4:

The reviewer said that the project is complete

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer commented collaboration is clearly explained in the slides, and the team has very good coordination with partners.

Reviewer 2:

The reviewer said the team appears to have close, appropriate collaborations as well as coordination with other institutions (e.g., Montana State University and Mercedes-Benz).

Reviewer 3:

The reviewer remarked there are collaborations across national laboratories, a university, and industry.

Reviewer 4:

The reviewer said that the collaboration is reasonable.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer said the project "Composite Cathode Architectures Made by Freeze-Casting for All Solid State Lithium Batteries" has ended (March 31, 2021). This reviewer found that cathode-SEIs are incredibly important and deserve special attention from the DOE.

Reviewer 2:

The reviewer asked if there was any effort to investigate enabling chemical bonding between NMC and LLZO. NMC does expand and contract 10% or so during lithiation-delithiation, thus a chemical bond might be helpful.

Reviewer 3:

The reviewer said the project has ended.

Reviewer 4:

The reviewer remarked the project ended on March 31, 2021.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer remarked this project is relevant to a number of DOE objectives, namely, the objective to develop affordable batteries with increased energy densities (or specific energies) for applications in the EV market. Although this project aims to address this objective, there is still more work to do, as cathode/SEI still present numerous issues in different battery systems. While this project achieved greater than 100 Wh/kg batteries, the project did not move past the go/no-go stage because the energy density was presumably too low using the approaches outlined in the presentation. This reviewer noted that more funding will be necessary to try other types of architectures and further scale the production of these architectures. In total, this project addresses many of the DOE goals. This reviewer found that cathode-SEIs are incredibly important and deserve special attention from the DOE.

Reviewer 2:

The reviewer said aligned porous structure for an SSE is highly relevant to the DOE objectives in developing next-generation energy storage devices such as SSBs.

Reviewer 3:

The reviewer said the project is highly relevant.

Reviewer 4:

The reviewer commented that although LLZO has very good electrode stability and high ionic conductivity, the material integration and cell level assembly are very challenging. This project aimed to solve this issue for the practical application of SSBs. It supports the overall DOE objective in clean energy storage and the wide adoption of EVs.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer said the team was able to meet most of the milestones despite COVID-19. This team has the proper equipment and resources to carry out this research, and this team also has a number of active collaborations both internally and externally. These collaborations can help expedite this work if the team continues to receive funding from future calls. This reviewer found that cathode-SEIs are incredibly important and deserve special attention from the DOE.

Reviewer 2:

The reviewer remarked that there are good resources for this effort.

Reviewer 3:

The reviewer stated that LBNL has great resources for the team and the project.

Reviewer 4:

The reviewer commented that the team has lab resources to complete the milestones set in the proposed work including sintering, infilling, cell assembly, and battery testing. For troubleshooting, more characterizations and conductivity measurements might be helpful.

Presentation Number: bat507
Presentation Title: Controlled Interfacial Phenomena for Extended Battery Life
Principal Investigator: Perla Balbuena (Texas A&M)

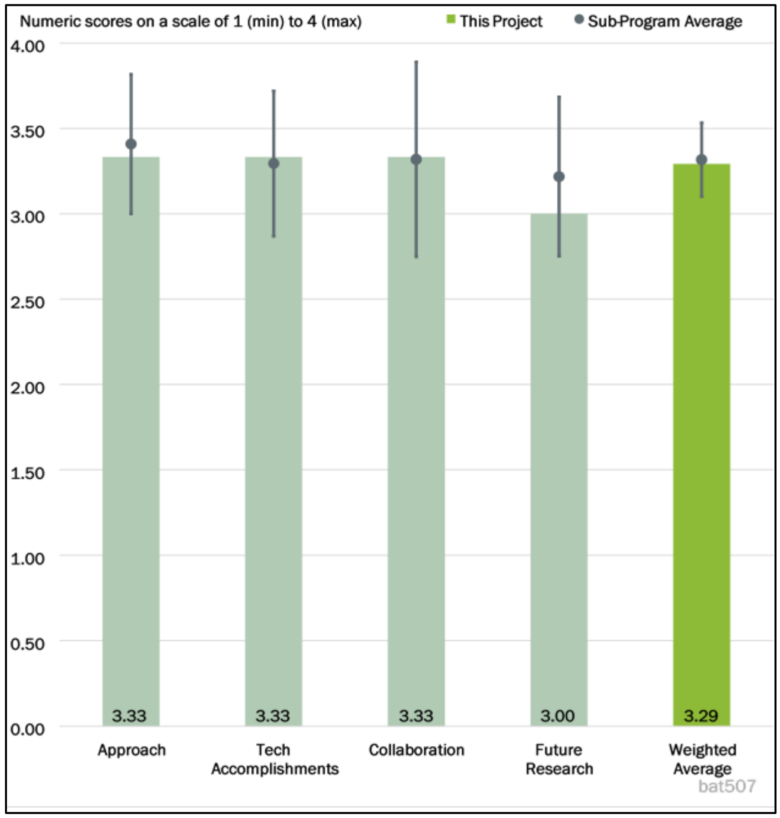


Figure 2-63 - Presentation Number: bat507 Presentation Title: Controlled Interfacial Phenomena for Extended Battery Life Principal Investigator: Perla Balbuena (Texas A&M)

Presenter

Perla Balbuena, Texas A&M

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer remarked the team uses extensive ab-initio molecular dynamics and molecular dynamics simulations to investigate the effect of salt concentration on Li-ion transport in batteries in the presence of an electric field. The team is using the information to provide possible mechanisms for Li transport and guidance for optimum electrolyte compositions. The reviewer asserted that this was great work.

Reviewer 2:

The reviewer found that overall, the approach seems strong. There is detailed work on electrolyte structure and ion-transport mechanisms, and the results appear to be well documented in journal publications. Collaboration with other research groups is important. This reviewer did not see a list of milestones in the presentation, which made it hard to tell if the approach is clearly aimed at addressing the milestones.

Reviewer 3:

The reviewer noted how the team uses ab initio molecular dynamics (AIMD) to study the ionic conductivity in electrolytes. While improved fundamental understanding helps in technical developments, the research should be aimed at predicting new materials for high ionic conductivity electrolytes.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer said the team has developed some new understanding of ion-transport mechanisms in electrolytes. It is expected that the team will be able to provide theoretical guidance to control the interface phenomena to extend battery life.

Reviewer 2:

The reviewer noted a large number of insightful results from state-of-the-art computational work and in-depth analysis work. The reviewer posed a few questions about the presentation: First, how long are the molecular dynamic (MD) simulations for ionic conductivity? Enough statistics? Second, what is the dependence of the results on initial configurations? Are the results independent of initial configurations? Third, how can Li Fermi level change with SEI? Li being a conductor?

Reviewer 3:

The reviewer remarked the presentation is somewhat hard to follow, as the slides are quite busy and this is not the reviewer's exact research area. That said, the results are addressing important electrolyte systems and concepts and there are numerous publications in which the work is presented.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer commended the project team for collaboration with PNNL teams. It is the right direction to work with experimental teams to explain experimental results and to explore new materials or approaches to synthesis of new materials.

Reviewer 2:

The reviewer said collaborations provided possible SEI and cathode-electrolyte interphase (CEI) compositions for high concentration electrolytes, which is a very challenging task.

Reviewer 3:

The reviewer said there is collaboration with PNNL, but the slides give the impression the collaboration is primarily occasional discussions rather than joint planning of work, which would probably be more impactful.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer remarked proposed future work is very challenging given the complexity of the SEI and CEI compositions and structures. The results might depend on the specific compositions and structures used to model the SEI and CEI.

Reviewer 2:

The reviewer said the team has provided a detailed plan for further evaluations of ion transportation of various liquid electrolytes. Since solid electrolytes are currently the research trend, the team should also consider applying the simulations in solid electrolytes.

Reviewer 3:

According to the reviewer, the proposed future work is rather generic, and it would be helpful if there were also more specific future work specified to help evaluate how it ties into the milestones and project objectives. As written, the future work is more open ended.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer said the work presented in this project supports the efforts of scientists in the battery community by providing useful insights and fundamental understanding that will lead to better formulations and battery performance. This project supports the overall DOE objectives.

Reviewer 2:

The reviewer commented this is one of the few battery research teams doing theoretical work. Good theoretical work will provide guidance to technical developments.

Reviewer 3:

The reviewer said that, yes, it is addressing ion transport.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer remarked the amount of effort and time required to conduct this task is quite substantial. The complexity and the attention to details needed in this project might profit from extra funding.

Reviewer 2:

The reviewer said resources appear sufficient.

Reviewer 3:

The reviewer commented the team has sufficient resources.

Presentation Number: bat508
Presentation Title: Design, Processing, and Integration of Pouch-Format Cell for High-Energy Lithium-Sulfur Batteries
Principal Investigator: Mei Cai (General Motors, LLC)

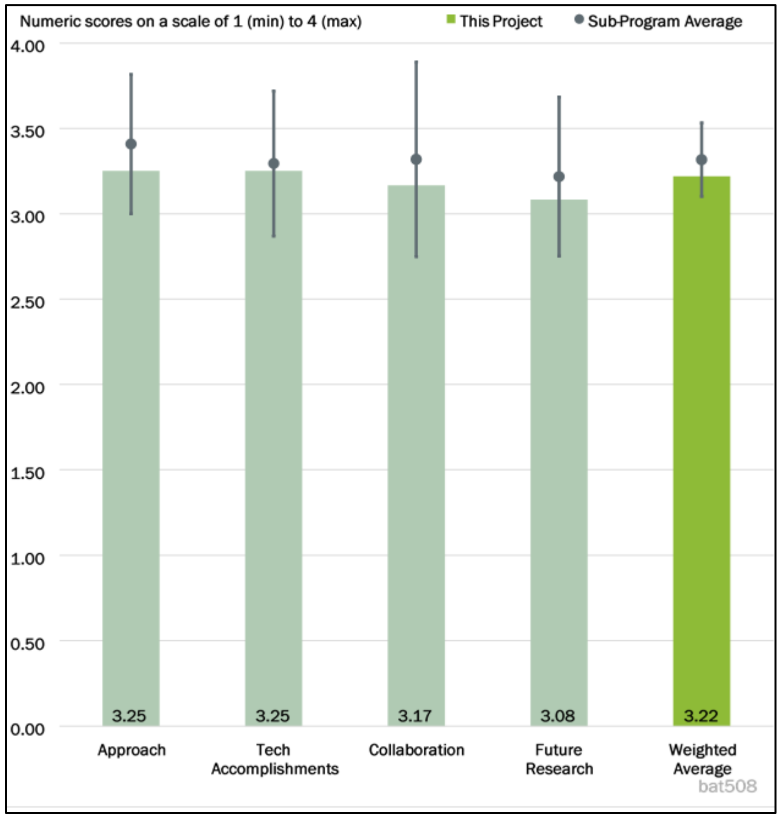


Figure 2-64 - Presentation Number: bat508 Presentation Title: Design, Processing, and Integration of Pouch-Format Cell for High-Energy Lithium-Sulfur Batteries Principal Investigator: Mei Cai (General Motors, LLC)

Presenter

Mei Cai, General Motors, LLC

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer remarked this project focuses on key barriers of developing high-energy Li-S batteries. The proposed approaches of cathode binder, electrode processing, separator coating, and dual-phase electrolyte are important and relevant to the performance improvement of Li-S cell.

Reviewer 2:

The reviewer said the approach to the work is sound. The high S loading objective, reduced porosity electrode, and polysulfide shuttle technical barriers were addressed. The energy density was promising though far below what is hoped for a Li-S system so room remains for further work to optimize.

Reviewer 3:

The reviewer remarked it appears that General Motors (GM) is interested in understanding the Li-S system and that it has in-house capabilities for making electrodes and cells. The approach has been to make S electrodes on dual-side coating equipment and then make a cell that addresses well-known problems of Li/S, like polysulfide migration to the anode. Subsequently, the team investigated a separator that helps mitigate sulfide migration. It is also investigating systems with an electrolyte for the cathode and a separate one for the anode.

Reviewer 4:

The reviewer said that this project aims to development a number of solutions to address the key challenges of Li-S batteries, including S cathode optimization, electrolyte or separator optimization, and pouch cell fabrication and testing. The cathode optimization seems to focus on improving the contact within the cathode and with the current collector. Additives that may be used to physically or chemically absorb dissolved polysulfides may be considered in the cathode optimization. The reviewer noted that the electrolyte design focuses on developing dual-phase electrolytes (polymer and liquid electrolytes), but this process will likely complicate the cell fabrication process.

Reviewer 5:

The reviewer commented that because the polysulfide-trapping interlayer may take S away from contributing to energy storage, an approach based on blocking polysulfides may be more effective.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer remarked that progress forward toward the overall project was good and meets the technical objectives laid out for this project.

Reviewer 2:

The reviewer noted that this group was successful in coating a S carbon electrode with high S content (70%) and found that separator being used provided good cyclability——the cell starts above 1,100 mAh/g and gradually declines to just under a 1,000 mAh/g after 60 cycles. It seems that the CE is declining at the same rate as the capacity, which for this reviewer is a little worrisome. The team has initiated some investigations into dual electrolytes that show better performance than a typical liquid electrolyte system. However, it looks like these systems die at around 100 cycles. The team has a new dual-electrolyte system that shows stable cycling to 350 cycles but at only 600 mAh/g. Overall, remarked the reviewer, it looks like the company is getting on its feet in Li-S and is trying some new ideas out but no great results yet to speak of.

Reviewer 3:

The reviewer said that materials scale-up has been achieved at the kilogram per batch level. Equipment for continuous electrode processing and surface coating have been set up and was used for large-areal electrode fabrication. Separator coating shows positive effect on capacity retention and mass transport, but mass contribution of the coating layer should be considered and minimized. The reviewer said that the durability of the dual-phase electrode needs more detailed study, particularly the phase stability for long time testing and how to maintain the two separated phases inside a real coin or pouch cells.

Reviewer 4:

The reviewer was unclear what the "complete solution" is in the sentence, "Small businesses or institutes could benefit from this complete solution, thus reducing the effort required for their own development work on the system." The amount (mass and volume) of the dual-phase electrolytes used to achieve the performance reported in the poster presentation was also unclear to the reviewer.

Reviewer 5:

The reviewer noted that in the past year, the team has been developing scale-up synthesis of carbon-S composite and R2R fabrication of S cathodes. The team also developed a metal oxide/carbon coated separator to suppress polysulfide shuttle. The team implemented a dual-layer electrolyte in the cell to protect Li. No pouch cell data were included in the report. Based on the existing data (6 mg/cm^2 S, approximately 1,200 mAh/g capacity, dual-layer electrolyte, 100 micron [µm] Li), it is also questionable that the team can approach or even come close to the proposed target.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said the project has close collaborations with universities, a national laboratory, and industry.

Reviewer 2:

The reviewer noted that the team has collaborated with a number of partners from national laboratories, universities, and industry.

Reviewer 3:

The reviewer said the collaboration appears to be okay across the project team. It was not specifically addressed in the poster other than naming the collaborators.

Reviewer 4:

The reviewer commented this is a large company that is trying to protect IP and just getting started so the team is not ready to bring in additional help yet.

Reviewer 5:

The contributions from II-VI Incorporated and Miltec UV International are not evident from the poster presentation.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer remarked that considering the challenging system, an appropriate approach is laid out. It might be difficult to implement and expensive considering its complexity.

Reviewer 2:

The reviewer noted that the future research will focus on a new dual-electrolyte system and will try to improve its performance—capacity and cycle life. This cell will be at 6 mAh/cm^2.

Reviewer 3:

The reviewer said the amount (mass and volume) of electrolyte should enter the calculation of capacity and energy density of the full cells.

Reviewer 4:

The reviewer said this project has clearly planned future work. The chemical and phase stability of the dual-phase electrolyte and issues associated with use of such electrolyte in practical cells should be carefully considered and addressed. Functionality of a dual-phase electrolyte should be validated in a S/C electrode since both SPAN and short chain S cathodes have much less polysulfide dissolution compared to S/C. The reviewer suggested that the S/C cathode should be the focus of the future work to achieve high cell-level energy.

Reviewer 5:

Because it is close to the end of the project, instead of further exploring another cathode such as sulfurized polyacrylonitrile (SPAN), or other dual-electrolyte designs, the reviewer recommended that the team integrate the best results into a pouch cell and see how it looks, i.e., integrating the best S-C cathode, best electrolyte design, and best separator into a pouch cell with an EV-relevant capacity (e.g., 2 Ah). The team will also need to study the effect of the test protocol on the pouch cell performance, as the team proposed. The reviewer noted that results will help VTO and the battery community to understand the current status of liquid electrolyte Li-S battery development.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer remarked this project supports the development of next-generation Li battery and thus aligns well with DOE's objectives of vehicle electrification.

Reviewer 2:

The reviewer pointed out that enabling a Li-S system has the potential to reach dollar per kilowatt-hour metrics owing to the low cost of S and the high potential energy density of such a system if enabled with high loadings of S and long cycle life.

Reviewer 3:

The reviewer commented that the project supports the Battery500 program.

Reviewer 4:

The reviewer said this project will help development of high energy density Li-S batteries for EV applications.

Reviewer 5:

The reviewer noted that DOE is spending a significant amount of resources on Li-S in Battery500, so this is certainly a chemistry of interest. GM is looking to improve this system.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer remarked the resources were sufficient for this project.

Reviewer 2:

The reviewer commented this is a difficult chemistry with no promise of success. GM is using its Li-ion equipment and some new ideas to try to get it to work. This must be a comfortable level of resources.

Reviewer 3:

The reviewer said the team has sufficient resources to complete the work.

Reviewer 4:

According to the reviewer, the team itself and collaborators have sufficient resources to execute the proposed research.

Reviewer 5:

The reviewer stated the team has ample resources.

Presentation Number: bat510
Presentation Title: Electrochemically Stable High Energy Density Lithium-Sulfur Batteries
Principal Investigator: Prashant Kumta (University of Pittsburgh)

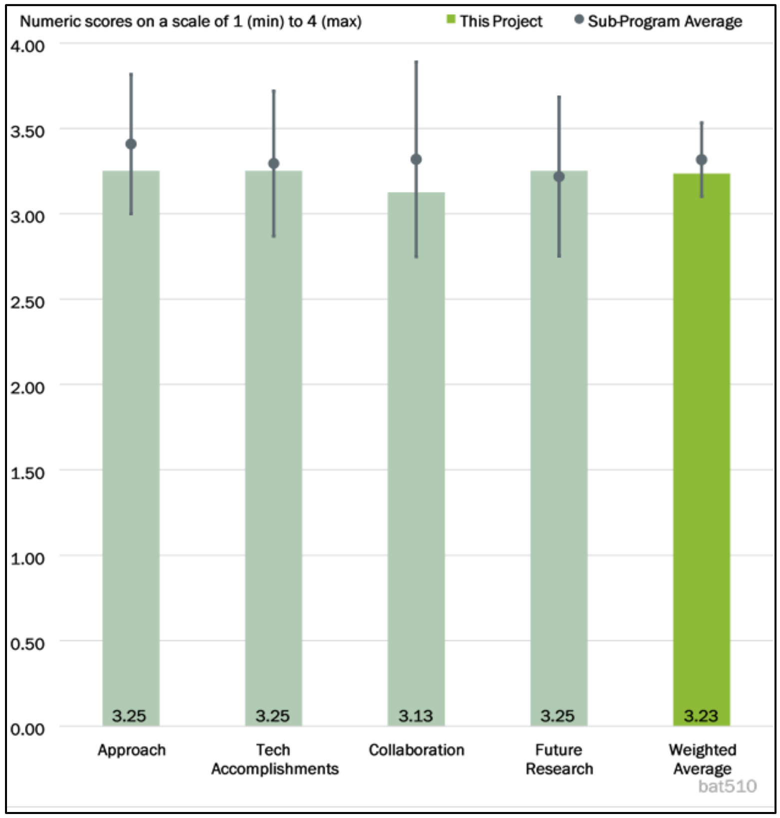


Figure 2-65 - Presentation Number: bat510 Presentation Title: Electrochemically Stable High Energy Density Lithium-Sulfur Batteries Principal Investigator: Prashant Kumta (University of Pittsburgh)

Presenter

Prashant Kumta, University of Pittsburgh

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 25% of reviewers felt that the resources were sufficient, 75% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer said overall, this appears to a challenging project with a good approach. A variety of technical approaches are made to improve the operation of the Li/S battery, and commercially relevant designs and evaluation criteria are used to assess the approaches.

Reviewer 2:

The reviewer said the approach used to develop and synthesize cathode materials that can meet the targets for this project is interesting as it is trying to make use of functionality, catalysis, and dispersion. For this end the approach uses a Li-ion conductor and functional electro-catalysts dispersed complex framework materials (with composition 90 weight percent [wt.%] S) to improve the reaction kinetics of high order polysulfides (PS) conversion to low order PS. The approach will rely on multiple parameters to optimize the composition and structure of the cathode.

Reviewer 3:

The reviewer remarked the combination of the lithium-ion conductor (LIC) coated complex framework materials (CFM) and the dendrite-free lithium-structurally isomorphous alloys (Li-SIA) seems to be working well in making high-energy density Li-S batteries. The CFM used by the team is supplied by others. The team should try to develop the CFM with equivalent or better properties on its own or secure a domestic supply chain for the precursors.

Reviewer 4:

The reviewer noted a well-designed, systematic work to design and fabricate high loading (equal to or greater than 6 mg/cm^2) S-rich CFM electrodes (equal to or greater than 63 wt% S in the electrode) exhibiting high areal capacity (approximately greater than 5 mAh/cm^2) and excellent cyclability (over 100 cycles) and to combine the electrodes with a dendrite-free, Li alloy anode in both coin cell and pouch cell configurations. The reviewer said there was not enough information on plans for how to overcome limited cycle life, capacity fade, and low CE by forming stable SEI and CEI layers in surface-engineered and scaled-up electrodes to reach energy density equal to or greater than 500 Wh/kg and a cycle life of approximately 1,000.

*Question 2: **Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.***

Reviewer 1:

The reviewer said the project shows good results. The milestones listed are very aggressive for a project of this size, and the reviewer did not think the presentation includes data showing some of the milestones being reached. For example, the reviewer did not see data for the December 2020 go/no-go although it is marked as completed. The results shown have areal capacities of around 3.5–4.5 mAh/cm^2, not the 6 mAh/cm^2 that is stated. However, the fact that both single-layer and multi-layer cell results are shown is quite impressive. The reviewer said it would have been helpful if the project team had provided the gaps remaining as the team comes to the end of the project and thoughts on whether or how those gaps may be addressed. Also, the reviewer did not see a definition of Li-SIA; the reviewer asked what the composition of the anodes is. It appears to be some type of alloy.

Reviewer 2:

The reviewer said the team has tested the 100-mAh single layer and 250-mAh four-layer pouch cells up to 60 cycles. The electrochemical stability for higher cycle numbers is still to be tested or improved. The cell capacity of the cell is not proportional to the number of layers, even though their energy densities are comparable.

Reviewer 3:

The reviewer remarked several accomplishments and demonstrations of the concept were already shown, and the project is in good progress. The reviewer posed questions and had comments about the presentation. Regarding the sentence on Slide 22, "Improve reaction kinetics and sulfur utilization by microstructure engineering," (Slide 22), the reviewer asked if it is possible to estimate how much microstructure engineering and improvement of reaction kinetics will improve the performance. The reviewer noted that using computational modeling to improve the reaction kinetics is a great place to start. Do you expect further complexity for the synthesis and optimization of the functional catalysts?

Reviewer 4:

The reviewer said the team has demonstrated several technical accomplishments and progress in the overall project. The project is in a great shape in terms of milestones and publications. The team has developed a high throughput, high yield, commercially inexpensive process for the synthesis of electrochemically stable S infiltrated CFM-S that enable high S loading (greater than 63 wt.%). LIC dispersed on nanocrystalline porous architecture of CFM shows excellent ability of trapping PS and maintaining ionic conductivity of the electrode with the high areal capacity of approximately 5 mAh/cm^2 and excellent cyclability (over 100 cycles). The reviewer asked if the team can describe the in situ optimization process for the bifunctional catalyst cathode material applied to achieve microstructure control of FEC within S grain or at the S grain boundary? The reviewer offered as a general comment that better characterization and imaging of carbon nanofiber (CNF) cathode material development to demonstrate S infiltration and microstructure control is needed. The reviewer noted that the Li-S single-layer pouch cell shows significant capacity fade: 0.28% per cycle at 0.1C and limited cycle life. A challenge still remaining for the team is to fabricate single-layer/multi-layer (approximately 20 cm^2) pouch cells with energy density greater than or equal to 500 Wh/kg and a cycle life of 1,000 cycles. The reviewer asked how this work with liquid electrolyte compares with the state-of-the-art solid electrolytes in achieving these goals.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said several collaborations are listed with specific tasks according to their expertise.

Reviewer 2:

The reviewer said that coordination appears to be good. It was hard to tell the exact contributions from the slides, although a good team appears to be assembled.

Reviewer 3:

The reviewer encouraged the team to collaborate with national laboratories to utilize modern structural and morphological characterization techniques (synchrotron and neutron).

Reviewer 4:

The reviewer said that the collaboration with the Nanomaterials for Energy Conversion Storage Technology (NECST) Laboratory–Energy Innovation Center in Pittsburgh on developing modified coin cell testing and carbon nanoarchitectures and developing pouch cell testing seems effective. The reviewer said the team should look into establishing more collaboration on materials characterization and imaging.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer noted that the future works includes an attempt to achieve cells greater than 500 Wh/kg. This has been the goal of the Battery500 program, but it seems a really challenging goal for an approximately $1 million project at a university. In the slides the project team shows less than half of that target and has 6 months left in the project. It may be more appropriate to focus on smaller cells and knowledge generation.

Reviewer 2:

The reviewer said there is a long way to go to reach the 500-mAh target. The team is aware of the challenges, but the future plan does not have enough details.

Reviewer 3:

The reviewer noted ambitious future plans on multi-layer pouch cells meeting the targeted capacity of greater than 6 mAh/cm^2 and exhibiting stable cycle life of 1,000 cycles followed by design and testing of 500 mAh (0.5 Ah) multi-layer pouch cells with initial targeted energy density of more than 500 Wh/kg. Safety field testing will be performed on approximately 100 mAh single-layer pouch cells (greater than or equal to 500 Wh/kg) in collaboration with PNNL and an industry partner, and 12 test cells meeting the performance and safety standard will be delivered to DOE.

Reviewer 4:

The reviewer commented that proposed future work should lead the project to completion. Major challenges are still present as mentioned in the “Challenges” section. Demonstration of successful generation of multi-layer pouch cells matching single-layer performance is a good start.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer noted that Li-S batteries can be used for high-capacity energy storage. The efforts to make better Li-S battery support the DOE objectives.

Reviewer 2:

The reviewer said this work is in line with DOE-Battery500 goals to fabricate, evaluate performance, and optimize 20 cm^2 pouch cells of cell capacity more than 100 mAh and target energy density (greater than or equal to 500 Wh/kg).

Reviewer 3:

The reviewer affirmed that the project goals align with DOE objectives.

Reviewer 4:

The reviewer remarked the team is working to develop high-energy Li-S cells.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

The reviewer said great progress was made and the approach seem reasonable and worth pursuing.

Reviewer 2:

The reviewer remarked resources and expertise seem sufficient to achieve proposed milestones.

Reviewer 3:

The reviewer commented that given the really ambitious milestones, it is hard to see how a project of this size has a real shot at hitting them within the project period. The team should consider scoping the work differently.

Reviewer 4:

The reviewer found that at the 90% completion of the project, the team has not reached the planned objectives.

Presentation Number: bat511
Presentation Title: High-Energy Solid-State Lithium Batteries with Organic Cathode Materials
Principal Investigator: Yan Yao (University of Houston)

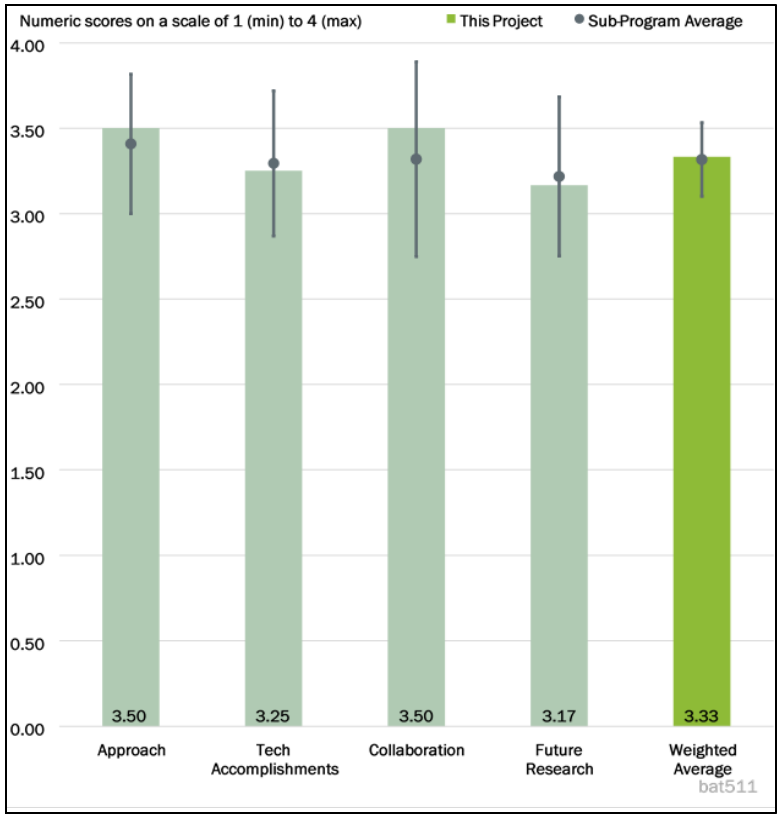


Figure 2-66 - Presentation Number: bat511 Presentation Title: High-Energy Solid-State Lithium Batteries with Organic Cathode Materials Principal Investigator: Yan Yao (University of Houston)

Presenter

Yan Yao, University of Houston

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 83% of reviewers felt that the resources were sufficient, 17% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

Developing high-voltage, high-capacity organic cathodes is important to improve the energy density of batteries (not limited to SSBs) and lower the cost of electrodes by removing Co and nickel Ni. The project is well designed, and the proposed approaches are feasible.

Reviewer 2:

The reviewer noted that high-capacity organic-based cathode material is among the most important options for Co-free cathodes for next-generation energy storage technologies. An SSB is beneficial to addressing potential dissolution issues of organic-based cathodes. Focusing on electrode architecture and materials utilization is a correct direction. The reviewer said that intrinsic sluggish kinetics of this material would be a focus with possible approaches in hand.

Reviewer 3:

The reviewer noted that the approach uses a non-Co, non-Ni containing organic electrolyte, which has the potential to achieve the 500 Wh/kg project goal. It is unlikely to succeed commercially, but this is normal for early-stage exploratory research.

Reviewer 4:

From what this reviewer can tell, the researchers are making organic insertion materials that are softer than the electrolyte. When a composite electrode of the materials is compressed, it ends up with cathode material surrounding the electrolyte, which prevents a continuous path for ionic transport in the cathode. The reviewer noted that the team developed a solution-based process for encapsulating the active material in the electrolyte, and when this is compressed to form a compact electrode, the electrolyte forms a continuous path.

Reviewer 5:

The reviewer said that it is unclear what approaches the team is taking to address the commonly known problem of low electronic conductivity of organic electrode materials or organic insertion materials (OIMs), which may be rate limiting in fast charging.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer noted that the understanding of the microstructure enabled some improvements in performance. Reasonable progress toward the objectives was demonstrated.

Reviewer 2:

The reviewer said the team has demonstrated impressive specific capacity (milliamp-hours per gram [mAh/g] OIM) and specific energy (Watt-hours per kilogram [Wh/Kg]). What are the capacity (i.e., mAh/L) and energy density (Wh/L)?

Reviewer 3:

The reviewer remarked the team is on track to meet the proposed milestones. The utilization of the cathode active material was improved by the solution processing process. While the improved interfacial contact can lead to higher utilization of cathode active material, the utilization of the solution process also largely decreases the kinetics of the electrodes due to decreased ionic conductivity in the cathode composite. Even after annealing, the ionic conductivity of solution-processed solid electrolyte still has a much lower ionic conductivity. The reviewer said the team may consider alternative approaches to improve the contact while maintaining the ionic conductivity of solid electrolytes. The team also needs to consider the way to report the voltage of the electrode, i.e., majority of the discharge capacity of UH04 is observed below 2.7 V.

Reviewer 4:

The reviewer said that development of new OIM materials with improved capacity and working voltage is an important accomplishment. The team identified issues of component distribution inside the electrode and effective measures to address. Highly conductive SSE with small particle size is needed for this project.

Concerning the HU04 and HU08 materials test, this reviewer inquired about the mass loading, electrode composition, and current density. A cell test would be at more realistic conditions. In the estimation of cell energy toward 500 Wh/kg, density of solid electrolyte is 1.56 g/cc. The reviewer inquired about the kind of materials or separator porosity.

Reviewer 5:

The reviewer was a little concerned that the team is only achieving about 40% loading of the cathode while still having a rate issue. Unfortunately, the electrode with higher loading shows very poor rate capability. The team's overall loadings are below 1 mAh/cm^2, which is very low for a Li-ion cell, especially because the specific capacity is around 400 mAh/g. These results are after improvements. The reviewer said the team has identified higher energy materials with higher theoretical specific capacities and higher average voltages. The rate capability seems to be a bigger issue than the specific capacity. The reviewer was not sure if this is an electrolyte problem or what the team plans to do about it.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said coordination across the team appears to be working.

Reviewer 2:

The reviewer commented that the team has a reasonable number of collaborations and the ones it has are important to improving the cells.

Reviewer 3:

The reviewer said the team has a strong collaboration with national laboratories, universities, and industry.

Reviewer 4:

The reviewer remarked the PI has close collaborations across universities, national laboratories, and industry.

Reviewer 5:

The reviewer remarked the contributions from collaborators from Solid Power and Ampcera are unclear.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer said the project is near its end. The proposed future work is appropriate for that stage.

Reviewer 2:

The reviewer remarked the team may address the low electronic conductivity issue common to organic electrode materials.

Reviewer 3:

This project has clearly planned future work. The reviewer noted that more efforts would be focused on the new high-capacity, high-voltage cathode materials and cell test at practical conditions.

Reviewer 4:

The reviewer remarked the team's future work includes pursuing higher energy materials and incorporating them into cells. It seems like a hope that the rate capability will be better for the new materials as this reviewer saw no planned work to improve rate and the team plans to go to higher loadings, which will work against them.

Reviewer 5:

The team has made great progress in increasing capacity, voltage, and utilization of the organic cathode. However, the existing performance would not enable a 500-wh/kg cell which, based on the cell design, would need 65% active fraction, 501 mAh/g specific capacity, 12.2 mg/cm^2, and 2.9V. As a matter of fact, it is challenging to reach any of the four metrics, let alone all of them. Given the remaining project time, the reviewer recommended the team do a detailed analysis on the pathways to higher energy cells. Specifically, details—which parameter of the four more effectively can improve the cell energy and which of the four relatively can be improved—will be important for the community to understand the promise of organic electrodes for high energy cells.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer noted that the project is targeted toward a high energy battery, which does not use Co or Ni and thus addresses several project objectives.

Reviewer 2:

The reviewer said the project supports the Battery500 program.

Reviewer 3:

The reviewer commented that SSBs are a real challenge that DOE has elected to pursue due to the promise of improved safety and increased energy density. This work falls in line with this pursuit.

Reviewer 4:

The reviewer remarked the project will lead to low-cost, environmentally friendly cathode materials for next-generation batteries.

Reviewer 5:

The reviewer affirmed this project is closely related to the development of a high-energy Li battery, aligning well with DOE/VTO's objectives of vehicle electrification.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer said resources are sufficient for this project.

Reviewer 2:

According to the reviewer, the team has sufficient resources to complete the work.

Reviewer 3:

The reviewer commented the PI and team have sufficient resources for the proposed research.

Reviewer 4:

The reviewer stated that the team has excellent resources.

Reviewer 5:

The reviewer remarked the team has an interesting technology. However, this is a university-funded project and even though the team only put up 20% cost share, this is a difficult problem that will take more resources.

Presentation Number: bat512
Presentation Title: Highly Loaded Sulfur Cathode, Coated Separator and Gel Electrolyte for High Rate Li-Sulfur
Principal Investigator: Yong Joo (Cornell University)

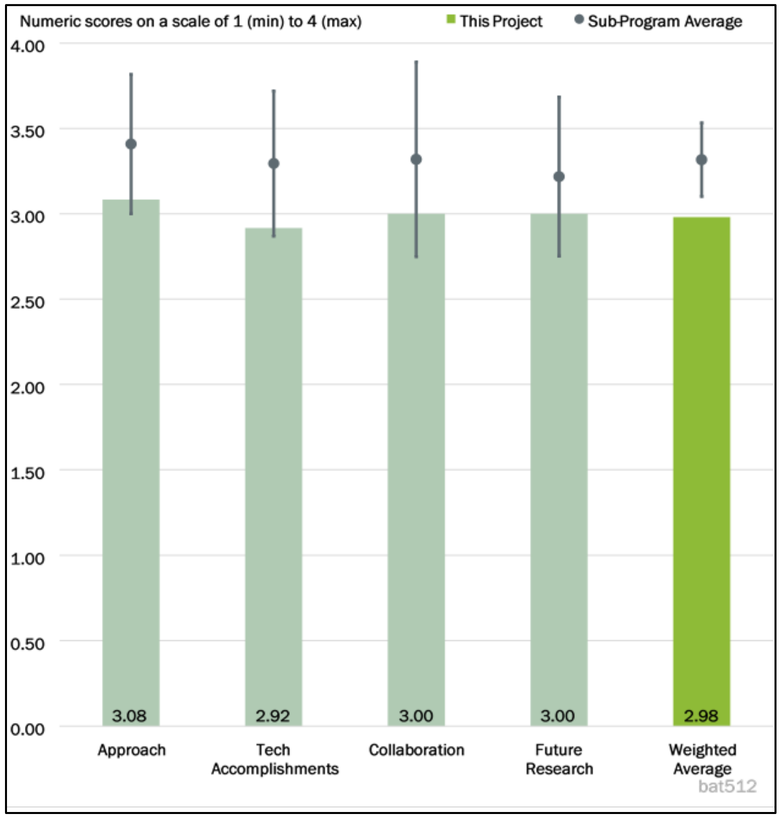


Figure 2-67 - Presentation Number: bat512 Presentation Title: Highly Loaded Sulfur Cathode, Coated Separator and Gel Electrolyte for High Rate Li-Sulfur Principal Investigator: Yong Joo (Cornell University)

Presenter

Yong Joo, Cornell University

Reviewer Sample Size

A total of six reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer remarked the approach is likely to be difficult to commercialize owing to its complexity. However, it does address the project objectives.

Reviewer 2:

The reviewer remarked that the proposed approaches for a high-loading S electrode, functional separator coating, and gel electrolytes are important and relevant to addressing key technical barriers of high-energy Li-S batteries. The techniques developed for S electrode fabrication and separator coating are unique and applicable to achieve the proposed technical targets. The reviewer noted that the two things that the project team may need to address are high porosity of the S cathode and parasitic weights of the separator coating, both influencing cell-level specific energy and energy density.

Reviewer 3:

The reviewer said the team proposed to optimize high S loading, separator, electrolyte, and pouch cell fabrication and testing to address the key challenges in Li-S batteries. The project is properly designed. Modifying electronic conductivity in the S cathode can improve utilization and trap PS, and developing a ceramic polymer separator can suppress the PS shuttle. Most of the approaches are reasonable, but the reviewer cannot understand the rationale for adding $LiFePO_4$ and $LiMn_2O_4$ in the S cathode to improve S utilization, as these two cathodes are typically considered not good electronic conductors.

Reviewer 4:

The reviewer commented that there are a number of challenges to getting full utilization and cyclability of a Li-S cell. From what this reviewer can tell, the approach is to (1) spray S onto either graphene sheets or carbon sheets and stack them together to make a cathode of high loading, (2) make a polymer-ceramic composite separator coated with graphene to prevent dendrites from growing across the cell (the polymer-ceramic) and prevent PSs from migrating into the separator (the graphene coating), and (3) infuse the separator with a gelable electrolyte to reduce the flammability of the cell. It is at least an attempt to deal with some of the major issues. It was not clear to this reviewer that the team will be effective.

Reviewer 5:

The reviewer remarked the approaches appear to be largely trial-and-error without clearly defined targets. For example, the poster showed an increase in the tensile strength of the polybenzimidazole (PBI) nanofiber (NF) separators from 12.3 MPa to 21 MPa by changing the infusion rate. However, is 21 MPa sufficient?

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer noted that with their cathode construction the team gets about 1,000 mAh/g of S at C/5. The team does not indicate the mass ratio of C to S of cyclable S, which is pretty good. The team produced an electrospun separator. With this separator and a gel electrolyte in the separator and an additive, the team demonstrated 1,000 mAh/g cyclability and believed that this is a safer cell than without the gelled electrolyte. The reviewer said the team only shows 20–30 cycles, with no indication of cell loading in milliamp-hours per square centimeter. It is not clear that the team has stopped the migration of polysulfides.

Reviewer 2:

The reviewer recommended that mechanisms responsible for the apparent effect of metal oxides on the S utilization should be explored. How does the team distinguish Li reversibly stored in LFP or LMO from Li stored in S? The team should use non-Li active oxides to help understand the effect of oxides on S utilization.

Reviewer 3:

The team has achieved good results to improve the utilization of the S cathode with a S content of 60%. Increasing the S content only will not necessarily lead to a high energy density cathode. The team should also consider and report the thickness or the areal capacity of the cathode. The reviewer expected to see a gradual increase of the areal capacity as the project moves along to the end, so the team should compare its own results in the past year, for example. The team also demonstrated the fabrication of a ceramic polymer separator and did the flammability test. The reviewer was not sure whether the flammability test is necessary because during cell fabrication the separator will still be infiltrated with flammable liquid electrolytes. It was also not clear to the reviewer how the electrospin-based separator synthesis can be scaled up. More characterizations on the separators, e.g., the porosity, or the amount of liquid electrolyte they can accommodate should be done.

Reviewer 4:

The reviewer noted that the PBI-alumina coated separator demonstrated improved electrochemical and mechanical properties compared with the Celgard separator. Introducing LMO and LFP into the cathode enhanced S utilization in high-loading S cathodes. Gel ceramic electrolyte with additional polyethylene glycol (PEG) had positive effects in suppressing PS crossover and reducing cell polarization. The reviewer said that to validate the developed cathode, coated separator, and gel electrolyte for pouch cells, realistic conditions like a high mass loading electrode and a lean amount electrolyte are suggested for cell test.

When LMO or LFP was used in the cathode, the electrochemical stability window of the liquid and gel electrolytes should be tested and verified, particularly for ether-based solvents like dioxolane (DOL). When exhibiting the cell capacity and cycling data, the reviewer suggested providing S loading, electrolyte/S ratio, and cell testing conditions.

Reviewer 5:

The reviewer commented that it appears that the objectives were not completely achieved. An extension has been granted to try to make further progress.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

According to the reviewer, the project team has good collaborations with university and industry.

Reviewer 2:

The reviewer said that collaboration appears to be satisfactory across the team.

Reviewer 3:

The reviewer acknowledged that this is a complicated system, but there are a few partners to help with different aspects of the cell design and construction.

Reviewer 4:

The reviewer suggested the team may consider using independent labs to help evaluate and verify cell performance and durability.

Reviewer 5:

The work so far was completed mostly at Cornell only, and the reviewer encouraged more collaborations.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer said the proposed work is appropriate to address the project objectives.

Reviewer 2:

The reviewer suggested that the team investigate the mechanisms responsible for the apparent effect of oxides on S-utilization.

Reviewer 3:

The reviewer said it seems a lot of work needs to be done in the remaining funding period. The reviewer recommended that the team focus on integrating its best cathode, separator, and electrolyte into a pouch cell and see what the performance looks like. The team also proposed to do a number of safety tests, and the reviewer thought that these tests should also be better done in a pouch cell format. Such information will help the VTO and the battery community to understand the status of liquid electrolyte-based Li-S batteries.

Reviewer 4:

The reviewer noted that the project has a detailed plan for the 6-month extension. Based on the progress achieved during the previous project execution, the proposed future research deserves extra time commitment. It would be interesting to integrate the developed cathode, separator, and electrolyte to see the energy limit of a pouch cell and then focus on cell cycling in future projects.

Reviewer 5:

The reviewer said the team proposed to optimize its system (no details provided) and perform rigorous safety testing. Without a cell that cycles 1,000 cycles, this reviewer did not think the team's priority should be safety testing. The reviewer noted that the team will produce large cells of 1–3 Ah and was unsure of readiness to move into scale-up of this technology.

*Question 5: **Relevance—Does this project support the overall DOE objectives? Why or why not?***

Reviewer 1:

The reviewer stated that the project may help reach Battery500 project goals.

Reviewer 2:

The reviewer affirmed that enabling Li-S supports DOE objectives to reduce dollars per kilowatt.

Reviewer 3:

The reviewer said this project will help develop high-energy Li-S batteries.

Reviewer 4:

The reviewer noted that Li-S is considered a technology that goes beyond Li-ion. Li-S has several issues preventing it from meeting USABC targets. This group is willing to try to address some of them.

Reviewer 5:

The reviewer said this project focuses on the development of a high-rate Li-S battery, which aligns well with DOE/VTO's objectives of vehicle electrification.

*Question 6: **Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?***

Reviewer 1:

According to the reviewer, resources are sufficient.

Reviewer 2:

The reviewer indicated that the team has sufficient resources.

Reviewer 3:

The reviewer said the team has sufficient resources.

Reviewer 4:

The reviewer remarked that the project team has sufficient resources to perform the proposed research, but a 6-month extension would very tight.

Reviewer 5:

The reviewer was unclear that what these researchers have done has resulted in any further progress than previous researchers, and was unconvinced that more in this direction will be fruitful.

Presentation Number: bat513
Presentation Title: Multifunctional Li-ion Conducting Interfacial Materials for Lithium Metal Batteries
Principal Investigator: Donghai Wang (Penn State University)

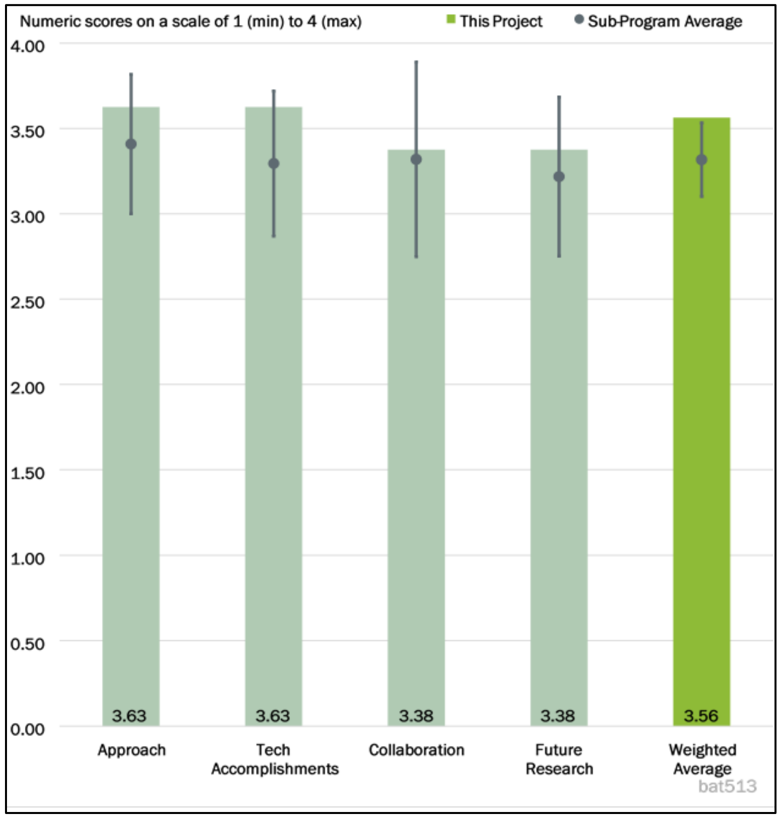


Figure 2-68 - Presentation Number: bat513 Presentation Title: Multifunctional Li-ion Conducting Interfacial Materials for Lithium Metal Batteries Principal Investigator: Donghai Wang (Penn State University)

Presenter

Donghai Wang, Penn State University

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer said this work uses polymer coatings and a new, carbonate-based electrolyte to protect the Li-metal anode. The approach is innovative and practical, and the polymer coating is scalable and compatible with a pouch cell.

Reviewer 2:

The reviewer commented that the team developed a new, ionic-conducting polymer interface to enhance the stability of the metallic Li-metal anode. The approach enables the use of metallic Li as an anode in organic liquid electrolyte-based LIBs. The project is well designed and feasible for real applications.

Reviewer 3:

The reviewer acknowledged a nice approach to try and make Li plating and stripping more uniform and efficient. There is a need to make sure the weight percentage of the non-active materials is relatively low.

Reviewer 4:

The reviewer said the approach of this project, as performed by Wang and co-workers, aims to develop multi-functional Li-ion conducting interfacial materials as a protective layer for Li-metal anodes, enabling Li-metal anodes to cycle with a high efficiency of approximately 99.9% at a high electrode capacity (4 mAh/cm^2) and a high current density (greater than 2 mA/cm^2) for 400 cycles. The main technical barriers addressed are (1) cycle life of Li-metal anodes and (2) voltage stability of the Li-metal anode. The reviewer said that while the project aims to demonstrate Li-metal battery cells with an energy density of approximately 300 Wh/kg and a greater than or equal to 80% capacity retention over 300 cycles using Li-metal anodes with the developed protective layer, the approach demonstrated by Wang and co-workers appears to partly fulfill this goal. The main approach entails two separate methods—novel polymer coatings onto Li metal anodes and electrochemically active mono-layers (EAMs). Overall, said the reviewer, the approach was demonstrated experimentally and appears to be a viable option to enable Li-metal batteries that cycle more than 240 times with 80% capacity retention at high areal capacity and lean electrolyte conditions. Further optimization of these materials can possibly extend the cycle life of Li-metal anodes.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer indicated that the polymer synthesis can be scaled up and next is demonstration of pouch cell performances. Overall, the project is making great process and is on track.

Reviewer 2:

The reviewer noted that significant improvement of cycling stability has been demonstrated after using an ionic conductive polymer protection layer between the anode and electrolyte. It seems that the Li dendrite growth was successfully prevented or delayed. It would be great to know how the system performs at higher charging rates.

Reviewer 3:

The reviewer said that there is a need to confirm that this approach to make current homogeneous is also mitigating dendrite growth. Liquid electrolytes should enable very homogeneous currents but still suffer from catastrophic dendrite shorting.

Reviewer 4:

The reviewer remarked that the project "Multifunctional Lithium-Ion Conducting Interfacial Materials for Lithium-Metal Batteries" reports a number of important accomplishments. This project led to (1) the development of a new hybrid Li-ion conductor that enables Li-metal anodes, (2) structure-property relationships of the new Li-ion conducting layers, and (3) macroscopic performance of the new interlayers under 0.2C and 0.5 C. The reviewer remarked while these technical accomplishments are impressive, more attention should be given to prevention of side reactions between the electrolyte and the Li-metal anode. Additionally, efforts should be directed toward suppressing Li dendrite/filament growth in under practical cycling conditions.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer said the team appears to have close, appropriate collaborations as well as coordination with other institutions (e.g., Ashland). This project also included collaborations within the lead PI's home institution (Pennsylvania State University [Penn State]). Overall, the work appears to be well coordinated.

Reviewer 2:

The reviewer remarked the collaboration looks good. The team has initiated collaboration with industry for scaling up the Li-ion conducting materials. The project has collaborators for performing modeling work.

Reviewer 3:

The reviewer said the collaborations between the PI and partners are clearly stated. Ashland is helping on scaling up the reactive polymer synthesis.

Reviewer 4:

The reviewer saw no issues with collaboration.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer said the project "Multifunctional Lithium-Ion Conducting Interfacial Materials for Lithium-Metal Batteries" will end on September 30, 2021. The proposed future work includes the demonstration of pouch-type cells with Li-metal anodes with a cycle life 300 cycles under high-capacity (4 mAh/cm^2), lean-Li (two-fold excessive Li), and lean-electrolyte (4 µL/mAh) conditions. Provided that this team has cycled cells 243 times with a capacity retention of 80%, this team should be able to meet this milestone in the coming months. The reviewer said adding excess Li and lean electrolyte will be important metrics for the proposed chemistry and design of the batteries, and these studies are strongly encouraged.

Reviewer 2:

The reviewer said the proposed future research focuses on pouch cell as well as practical conditions and is logical and appropriate.

Reviewer 3:

The reviewer commented the team is proposing to assemble and test pouch cells with leaner Li and electrolyte conditions, which is a logical move toward real application. Will the team evaluate the high-rate performance to enable fast charging of the Li-metal batteries?

Reviewer 4:

The reviewer said the team needs to confirm that this approach to make current homogeneous is also mitigating dendrite growth. Liquid electrolytes should enable very homogeneous currents but still suffer from catastrophic dendrite shorting.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer said the project is highly relevant to Li-metal anode development and commercialization.

Reviewer 2:

The reviewer remarked this project has a strong relevance to the DOE. Namely, the objective of this project is to develop affordable batteries with increased energy densities (or specific energies) for applications in the EV market. This project aims to address this objective by fabricating thin, dense, and uniform protective layers on Li-metal anodes. These layers are shown to have stability over a wider voltage range, and the layers were also demonstrated to have a specified level of scalability.

Reviewer 3:

The reviewer remarked that Li metal-batteries will be the next step beyond Li-ion batteries. This research focuses on protecting the Li anode and suppressing Li dendrites using a bottom-up polymer synthesis approach. The project is highly relevant to the overall DOE objectives.

Reviewer 4:

The reviewer noted that successful application of Li metal as an anode will dramatically improve energy density of the cells. Firing hazardous might be reduced if lean electrolyte was used in the cell. The efforts in the project will support DOE objectives for the improvement of EVs.

Question 6: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:

The reviewer noted that the team was able to meet most of the milestones despite COVID-19. This team has the proper equipment and resources to carry out this research, and this team also has a number of active collaborations both internally (through Penn State) and externally (Ashland). Overall, this team completed great work despite setbacks from COVID-19 and met most of the milestones to date.

Reviewer 2:

The reviewer found resources to be reasonable.

Reviewer 3:

The reviewer remarked that the team at Penn State has sufficient resources for the project.

Reviewer 4:

The reviewer said the team seems to have all necessary resources to complete the proposed work.

Presentation Number: bat518
Presentation Title: Solvent-free and Non-sintered 500 Wh/kg All Solid State Battery
Principal Investigator: Mike Wixom (Navitas Advanced Solutions Group)

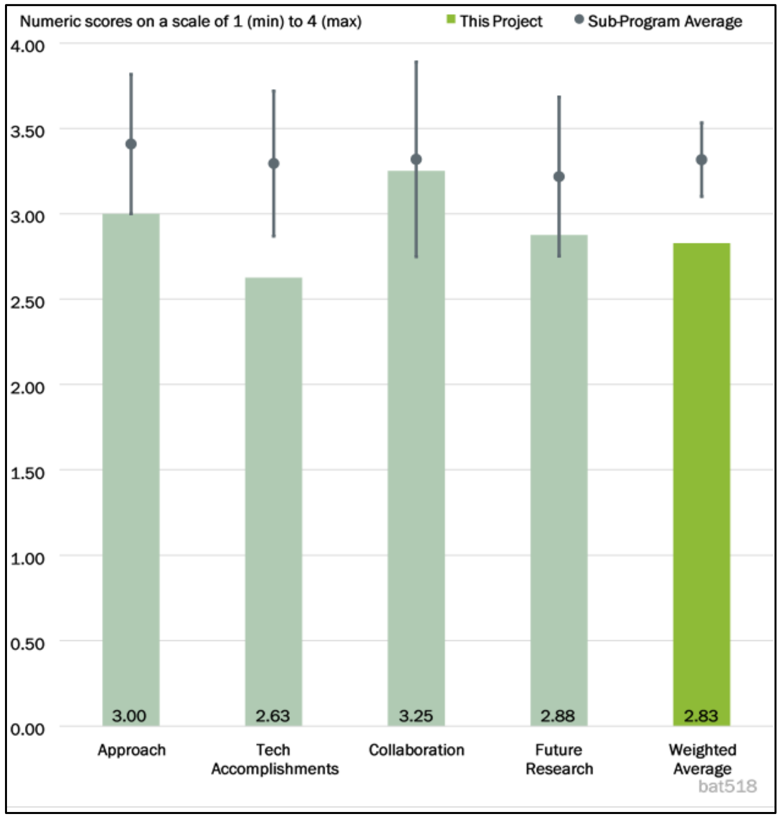


Figure 2-69 - Presentation Number: bat518 Presentation Title: Solvent-free and Non-sintered 500 Wh/kg All Solid State Battery Principal Investigator: Mike Wixom (Navitas Advanced Solutions Group)

Presenter

Mike Wixom, Navitas Advanced Solutions Group

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 75% of reviewers felt that the resources were sufficient, 25% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer remarked that overall, the approach is good. Existing materials are explored and modifications imparted to improve air stability. Attempts were made at commercially relevant loadings and other cell attributes. Clearly the team encountered some technical challenges that will prevent reaching the targets, however. The reviewer also noted that this was a clear and easy-to-follow presentation.

Reviewer 2:

According to the reviewer, the team's approach is to develop an advanced dry electrode process that enhances binder dispersion in SSB cathode and SSE films. This project will provide support to the Battery500 program to scale up the production of the materials.

Reviewer 3:

The reviewer said the project was well designed with a focus on addressing first material limitations and then processing challenges, but it was not executed.

Reviewer 4:

The project goal is to demonstrate a fabrication method for all solid-state Li-metal batteries to support the Battery500 program with similar performance to liquid-based systems. The reviewer was not familiar with the real technical challenges related to the fabrication. However, based on milestones and the overall presentation, the reviewer felt like more effort should be made to advance the project. Obviously, the pandemic delayed most of the work as shown in the milestones table. The reviewer did not have a chance to meet the presenter at the AMR (stopped by the poster twice) to get a better feel about the challenges.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer said that the project team is clear about what was able to be achieved and what was not. The team will not hit its 500 Wh/kg and 1,000 cycle goal, but of course this is the type of goal that requires more than a project of this size. Some progress in air stability and dry electrode technology was made, which is valuable. The reviewer noted that the team clearly learned more about the challenges in this field.

Reviewer 2:

The reviewer remarked that several milestones in FY 2020 and FY 202121 have been delayed. While this is understandable due to the pandemic, other teams have done better in conducting their projects in the same situation. The team has not found a way to optimize the NMC-SSE interface. The capacity retention of the NMC811 is disappointing. Also, the generation 2 LPS has a better ion conductivity than generation 1 but decays faster in the air than generation 1.

Reviewer 3:

The reviewer said the project was significantly delayed due to COVID-19. The team managed to optimize the dry electrode processes to improve the cycle life with enhanced binder dispersion, reduced binder content, and with the high throughput for industrial application with low cost.

The reviewer noted that surface protection on both cathode and Li anode is still investigated, though there has not been much progress with high loading NMC811 cell performance; the reviewer was doubtful the team will reach 1,000 cycles with 500 Wh/kg at room temperature by the end of the funding.

Reviewer 4:

The reviewer said the project started in 2017, and the reviewer is not confident about the amount of progress made so far. It looks like major challenges remain to be solved.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer said the team appears well composed with clear and important contributions from each team member.

Reviewer 2:

The reviewer remarked the team collaborates with national laboratories and universities.

Reviewer 3:

The reviewer noted that a number of collaborators have been listed; however, the reviewer was not clear about the amount of communication between the partners, as indicated by the remaining challenges listed in the presentation.

Reviewer 4:

The reviewer said that good collaborations are planned but not fully utilized.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer remarked proposed future work looks adequate and in line with the project goals, although very challenging.

Reviewer 2:

The reviewer said the team acknowledged the key tasks that remain in future work. The team also appears realistic that achieving the goals in the milestones will take longer than this project.

Reviewer 3:

The reviewer said the team is aware of the remaining challenges. Future research is proposed but there is a lack of detail to judge.

Reviewer 4:

The reviewer remarked major milestones from FY 2021 still need to be completed.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer said the project supports DOE objectives to demonstrate a R2R fabrication process incorporating stabilized sulfide SSEs, high-capacity cathodes, and protected Li-metal anodes that can deliver 500 Wh/kg specific energy and achieve life of 1,000 charge-discharge cycles.

Reviewer 2:

The reviewer commented the development of new fabrication methods that can help reduce cost and improve safety and performance will support the overall DOE objectives.

Reviewer 3:

The reviewer noted component and full cell development of 500 Wh/kg cells.

Reviewer 4:

The reviewer said the project provides support to the Battery500 program.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer remarked the team has sufficient resources to conduct the project.

Reviewer 2:

The reviewer said resources and expertise seem sufficient to achieve proposed milestones.

Reviewer 3:

The reviewer commented that with a goal of 2.5 Ah cells, 500 Wh/kg, and 1,000 cycles, there are not enough resources to reach that. The team made progress on several points in its work, but there is a big gap with this target.

Reviewer 4:

The reviewer noted that challenges seem to be in the optimization of the cell components.

Presentation Number: bat519
Presentation Title: Synthesis, Screening, and Characterization of Novel Low Temperature Electrolyte for Lithium-Ion Batteries
Principal Investigator: Xiao-Qing Yang (Lawrence Berkeley National Laboratory)

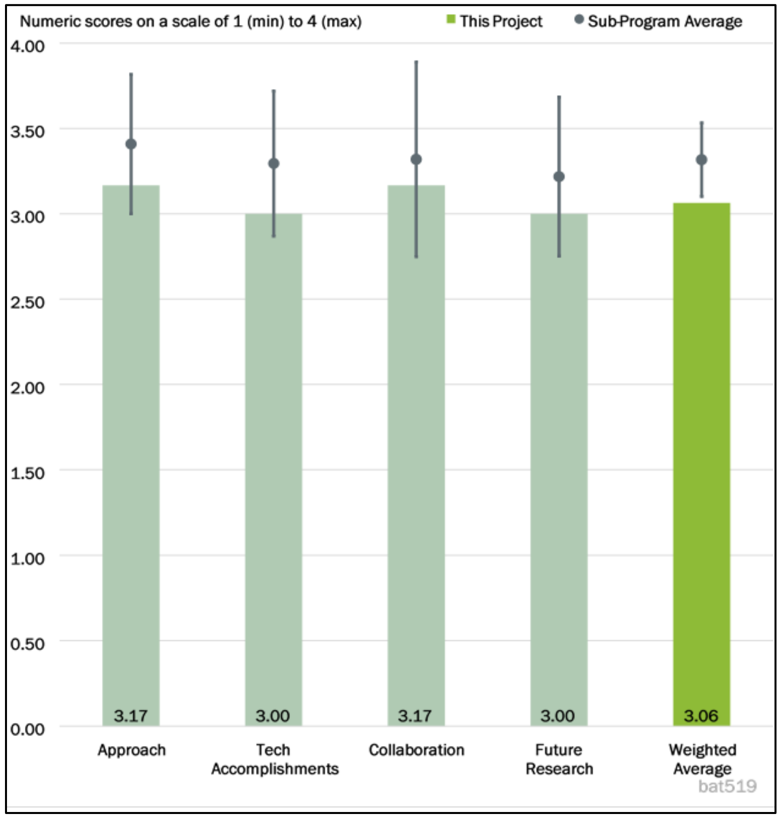


Figure 2-70 - Presentation Number: bat519 Presentation Title: Synthesis, Screening, and Characterization of Novel Low Temperature Electrolyte for Lithium-Ion Batteries Principal Investigator: Xiao-Qing Yang (Lawrence Berkeley National Laboratory)

Presenter

Xiao-Qing Yang, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer noted that electrolytes are needed that do better at low temperature, and this approach is a good one. There is a need to ensure that high-temperature (HT) stability does not suffer, and that is normally what happens with good low-temperature (LT) electrolytes.

Reviewer 2:

The reviewer asserted that the overall approach to performing work is solid, yet there is a minor element of an Edisonian approach in scouting for new electrolyte formulations. There is a good balance between testing and modeling. It is good see half-cell work included in the research.

The reviewer detailed that an Outstanding or Excellent score would have been given if the team had considered the thermodynamics of electrolyte phase behavior at lower temperatures, wherein there can be electrode surface-driven interactions with the electrolyte that promote larger scale aggregation within the electrolyte with possible solid phase formation at electrode surfaces. This is supported by the general observation that, in many cell chemistries, the adverse cell response to decreasing temperature has a higher activation energy than just the activation energy tied to electrolyte conductivity or diffusivity. Also, there was no mention of determining test artifacts such as charge-transfer resistance, a common metric that can help detect anomalous interfacial behavior such as LT phase transitions. Lastly, there is no mention of possible Li plating as a consequence of charging at lower temperatures.

Reviewer 3:

The reviewer said the team needs to provide a rationale for the various approaches. One approach seemed to be a combined exploration of various solvents and additives to enable high conductivity and low SEI impedance at low temperature. The team also proposed a combined approach of localized high-concentration electrolyte (LHCE) and low concentration electrolytes based on 1,1,2,2-tetrafluoroethyl-2,2,3,3-tetrafluoropropyl ether (TTE) solvent.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer noted that the project team's results showed the LT improvements due to the isoxazole (IZ) electrolyte and reported improvement due to 2 molar (M) lithium bis(fluorosulfonyl)imide (LiFSI)- ethyl methyl carbonate (EMC)/TTE concentrated electrolyte. Some explanations should be provided as to why the proposed LHCE and the low-concentration electrolytes did not improve LT performance. The reviewer highlighted that 2.2 mAh/cm^2 reported loading for the TTE was relatively light and the thinner electrodes might favor LT performance. The reviewer recommended that electrode loading should be reported also for the IZ electrolytes.

Reviewer 2:

The reviewer saw 10% FEC and explained that industry indicates a maximum FEC content of approximately 2%-4% due to gassing issues especially noticeable in larger automotive-sized cells.

Reviewer 3:

The reviewer found that overall, this team has noteworthy credentials. There was good delivery on the video and a good list of candidate electrolyte materials for enhancing LT performance. A minor portion of the poster presentation reflects a bit of random outcomes that do not seem well connected. The reviewer also noted that the use of LiFSI salt carries with it concerns of corrosion at the cathode current collector; so, this has to be well understood to prevent an incorrect diagnosis of cell performance.

This reviewer reported that Slide 7 indicates "An excellent ability of MD simulations using the revised APPLE&P force field to predict the Li+ solvation shell composition, diffusion coefficients of all species and temperature dependence of conductivity." Yet, such solvation shell and conductivity information were not divulged, especially at the desirable condition of -20°C. The reviewer noted that Slide 10 shows assessments at the C/5 rate. Should this actually be at C/3? The connection between Slides 12 and 13 is not clear, as the electrolyte used in Slide 12 is not given. The reviewer found a weak story involving higher T conditions: Slide 12 shows about 33% capacity loss (C/3 basis) at 100 cycles for 50°C. The reviewer noted that Li plating was not evaluated as a possible consequence of charging at lower temperatures.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer noted good collaboration with the University of Maryland, ARL, and University of Rhode Island with clear descriptions of the role of each team member.

Reviewer 2:

The reviewer encouraged some interaction with commercial cell builders to ensure these cells are relevant, and referenced a prior comment about FEC.

Reviewer 3:

The reviewer referenced prior comments, and remarked that the team has good credentials, but apparently missed some key issues relating to operating Li-ion cells at LT: possible surface-initiated solid phase behavior of the electrolyte, possible Li plating, etc. This outcome might have been corrected with better collaboration and coordination within the team and through reaching out to other experts in the field.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer asked if this LT electrolyte did the same or worse than the baseline electrolyte at higher T; normally, it is worse.

Reviewer 2:

The reviewer said this strikes me as being an Edisonian approach that does not mention or emphasize building on the knowledge gained by looking for the origins of poor LT performance. Without identifying such origins there is a lesser foundation for finding meaningful outcomes to mitigate poor performance at lower temperatures. There was no mention made of aging and/or survivability at up to 60°C.

Reviewer 3:

The reviewer said that per the stated objective to develop electrolytes that perform equally well at HT and LT, some future efforts need to be devoted to quantifying HT degradation of their optimized LT electrolytes.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer said weighing the collective responses expressed in earlier questions, this work supports DOE objectives for advancing the SOA for LT battery electrolytes, which if successful will help expand proliferation of LIB systems to greater geographical areas.

Reviewer 2:

The reviewer commented LT performance will become critical as EVs are more widely commercialized.

Reviewer 3:

The reviewer remarked the project has good objective to mitigate LT performance issues without compromising HT or fast charge rate capabilities.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer said that resources are sufficient given the nature of the team, its objectives, and schedule.

Reviewer 2:

The reviewer said $1 million per year should be sufficient to develop a wide-temperature range electrolyte.

Reviewer 3:

The reviewer had no comments.

Presentation Number: bat520
Presentation Title: Fluorinated Solvent-Based Electrolytes for Low Temperature Lithium-Ion Batteries
Principal Investigator: Zhengcheng Zhang (Argonne National Laboratory)

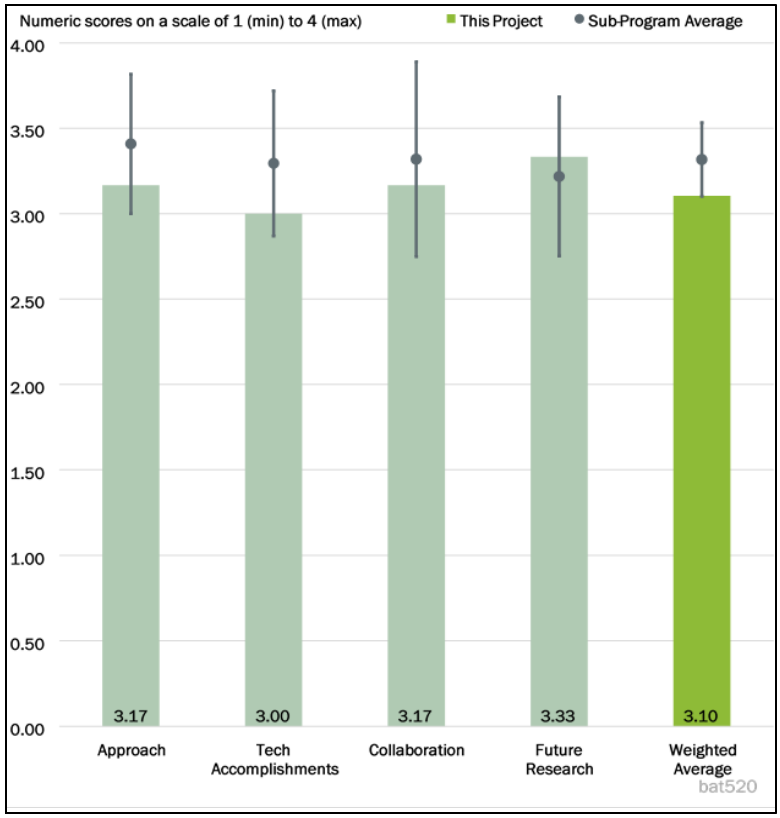


Figure 2-71 - Presentation Number: bat520 Presentation Title: Fluorinated Solvent-Based Electrolytes for Low Temperature Lithium-Ion Batteries Principal Investigator: Zhengcheng Zhang (Argonne National Laboratory)

Presenter

Zhengcheng Zhang, Argonne National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer said the proposed combination of additives to reduce SEI resistance and selected solvents to improve LT ionic conductivity is a sound approach.

Reviewer 2:

The reviewer commented the overall approach to performing work is suitable, yet there is an element of an Edisonian approach in scouting for new electrolyte formulations. What seems to be missing at this early stage is an emphasis on determining the origins of poor Li-ion cell performance at lower temperatures, as this is not simply a function of transport properties (diffusivity and conductivity) over the temperature regime.

The reviewer elaborated that an Outstanding or Excellent score would have been given if the team considered the following. Thermodynamics of electrolyte phase behavior at lower temperatures should be considered, wherein there can be electrode surface-driven interactions with the electrolyte that promote larger-scale aggregation within the electrolyte with possible solid phase formation at electrode surfaces. This is supported by the general observation that in many cell chemistries the adverse cell response to decreasing temperature has a higher activation energy than just the activation energy tied to electrolyte conductivity or diffusivity. Slide 3 mentions the topics of charge transfer resistance (RCT) and Li plating, and yet in the presentation that follows there is no mention of RCT (a common metric that can help detect anomalous interfacial behavior such as LT phase transitions), and there is no mention of possible Li plating as a consequence of charging at lower temperatures. The reviewer remarked these topics of RCT and Li plating should be part of the standard approach of core tools for inquiry into LT Li-ion cell performance.

Reviewer 3:

The reviewer remarked investigating esters is a reasonable approach for improving LT performance, but this has been done multiple times so it has to be a very focused investigation.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer said the team provided extensive data demonstrating the benefits of their fluorinated carbonate solvents and esters, in combination with additives such as FEC. The team's modeling provided good insights on how LT impacted ion pairing and solvation sphere that resulted in poor LT conductivity. The reviewer said the team should provide electrode loading to show that the good results were not due to thin light-loading electrodes.

Reviewer 2:

The reviewer said the team is well underway and showing overall good progress at only 33% complete. Although some deficiencies were noted, the reviewer had no doubt they could be remedied in future work.

The team has assembled a good list of candidate electrolyte materials for enhancing LT performance. Regarding electrolytes at 0.6M, the reviewer stated that this could lead to localized, dramatically starved electrolytes when cells undergo concentration polarization, a strong possibility at lower temperatures. This will produce a corresponding low-conductivity region (e.g., near the cathode surface during cell discharge). The reviewer recommended more studies over salt concentration. Regarding the use of butyronitrile (BN), the reviewer asserted that this carries with it an added toxicity burden that should be factored in, as feasible.

The reviewer said it was good to see cation solvation structure mentioned in this work. Regarding Slide 10, the reviewer asked if the detrimental results for LiFSI systems could be tied to the corrosive action of LiFSI. Regarding Slide 14, the reviewer wanted to know what modeling basis was used for electrolyte conductivity? Modeling results vary with experimental values by about 50%, showing a lack of modeling fidelity that will severely diminish using this modeling basis as a screening and/or learning tool. The reviewer referenced the residence times on Slide 14 and noted that these values are informative and their non-linear trends over temperature are much appreciated. The approach to studying electrolyte additives is logical and well performed.

The reviewer noted that in the video there was no audio for about the last 1.5 minutes, and there were no HT results yet. Cell data evaluations involving RCT were not performed but are highly anticipated for future work. Li plating was not evaluated as a possible consequence of charging at lower temperatures.

Reviewer 3:

The reviewer pointed out that 25% FEC is used here, which industry indicates is not possible in large pouch cells due to gassing. Industry limits FEC content to 2%–4% due to gassing.

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer said collaboration appears to be well managed and intact.

Reviewer 2:

The reviewer cited good collaboration with LBNL, and said that some descriptions should be provided on Navitas' contribution to the team.

Reviewer 3:

The reviewer recommended some collaboration or communication with commercial cell builders to ensure that electrolytes are commercially relevant.

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer remarked future work shows a favorable, effective combination of experimental and modeling work that will help build understanding of the origins of poor LT performance of Li-ion cells.

Reviewer 2:

The reviewer noted that all of these esters certainly improve LT conductivity, which has been known for years, and generally make 40°C and higher temperature life much worse; the gassing is often large. The reviewer would encourage this team to do higher T testing to ensure that life there is not compromised.

Reviewer 3:

The reviewer remarked per the team's stated objective to develop electrolytes that perform equally well at HT and LT, some future efforts need to be devoted to quantifying HT degradation of optimized LT electrolytes.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer said improved LT performance is highly relevant.

Reviewer 2:

The reviewer remarked weighing the collective responses expressed in earlier questions, this work supports DOE objectives for advancing the SOA for LT battery electrolytes, which if successful will help expand proliferation of Li-ion battery systems to greater geographical areas.

Reviewer 3:

The reviewer commented that there is a good objective to mitigate the LT performance issue without compromising HT or fast charge rate capabilities.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer observed sufficient resources.

Reviewer 2:

The reviewer said resources are sufficient given the nature of the team, its objectives, and schedule.

Reviewer 3:

The reviewer asserted that $700,000 per year should be sufficient to develop LT electrolytes.

Presentation Number: bat521
Presentation Title: Ethylene Carbonate-Lean Electrolytes for Low-Temperature, Safe, Lithium-Ion Batteries
Principal Investigator: Bryan McCloskey (University of California, Berkeley)

Presenter

Bryan McCloskey, University of California, Berkeley

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

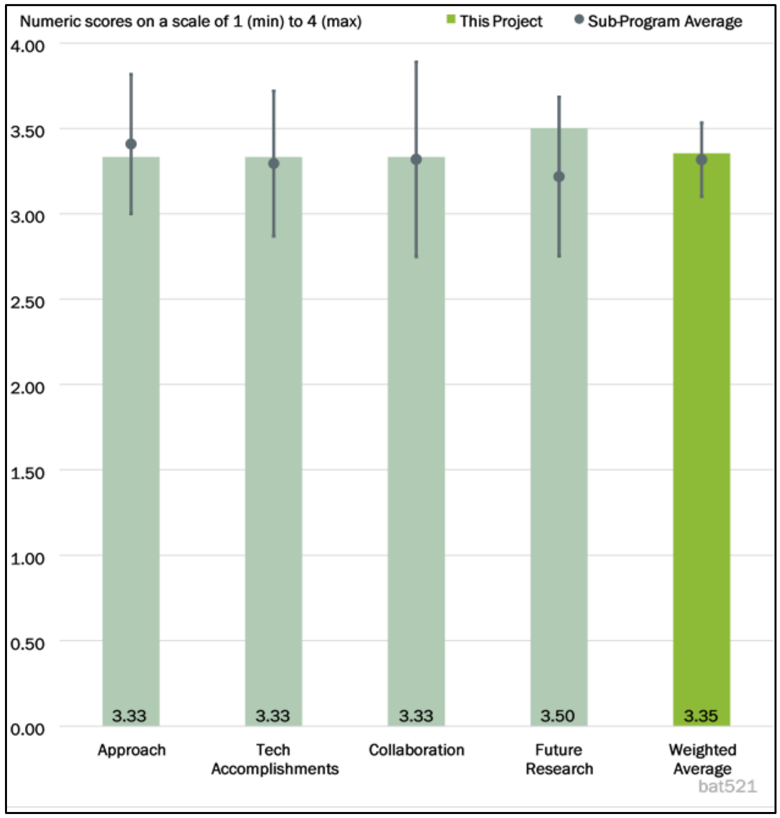


Figure 2-72 - Presentation Number: bat521 Presentation Title: Ethylene Carbonate-Lean Electrolytes for Low-Temperature, Safe, Lithium-Ion Batteries Principal Investigator: Bryan McCloskey (University of California, Berkeley)

Question 1: *Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.*

Reviewer 1:

The reviewer said that this is a very good approach to trying to improve LT performance.

Reviewer 2:

The team utilized the ANL Cell Analysis, Modeling, and Prototyping (CAMP) electrodes with practical loadings (more than 2.5 mAh/cm^2) that avoid skewing the findings for LT as is the case for low loading electrodes. Future electrolyte projects should be based on agreed, standardized electrodes from CAMP in order to compare the performance of various electrolytes. The reviewer said the team's combined approach of using electrochemical testing with ionic transport modeling for different concentrations and additives is a sound approach.

Reviewer 3:

The reviewer remarked the overall approach to performing work is solid, as it appears to capture the fundamentals of elucidating the origins of poor Li-ion cell performance at lower temperatures. There is a good balance between testing and modeling. Use of half-cell work in the research is a key feature to assign weight to cathode versus anode sensitivity to temperature conditions.

The reviewer noted that the emphasis on RCT at both electrodes is valuable in that it can be used to explore related factors such as the exchange current density. Such terms will help detect thermodynamic behavior of electrolyte phase transitions at lower temperatures, wherein there can be electrode surface-driven interactions with the electrolyte that promote larger scale aggregation within the electrolyte with possible solid phase formation at electrode surfaces.

Question 2: *Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.*

Reviewer 1:

The reviewer said the team's study provided great insights on the poor LT performance issue in Li-ion cells. The three-electrode study showed charge transfer at graphite anode dominating at low temperatures and their molecular dynamics modeling showed decreased conductivity due to increased ion pairing at low temperatures.

Reviewer 2:

The reviewer provided insight regarding the projects' question of finding an SEI additive to use with gamma-butyrolactone (GBL). In the past, many have used small amounts of ethylene carbonate (EC) (5%–10%) to form the SEI. However, GBL is known to introduce HT life and gassing issues, so the reviewer would be careful before pushing it much further.

The reviewer was glad that LBNL has limited FEC to 10% or less as industry has settled on about 2%–4% FEC due to gassing in large format automotive cells RCT dominates LT as both cathode and anode go high but anode dominates. The reviewer thought that this is exactly what Andy Jansen found 15 years ago in the Advanced Technology Development (ATD) program.

Reviewer 3:

The reviewer remarked that given that the work is about 50% complete, the extent of accomplishments and progress is on track and is along a logical progression. A key objective for FY 2021 is to understand the origin of resistances within Li-ion batteries at low temperature. Toward this goal, test methods and analysis techniques have been well demonstrated.

The reviewer found some noted deficiencies that will likely be resolved in future work:

- The team needs to greatly expand the list of candidate electrolyte solvents and salts.
- The team needs to develop more informative structure-function relationships to aid in co-solvent and salt selection.
- The team does not mention possible Li plating as a consequence of charging at lower temperatures and how to detect and mitigate this outcome.
- The team does not mention Li-ion cell survivability and aging at higher temperatures (e.g., 50°C).

Question 3: *Collaboration and Coordination Across Project Team.*

Reviewer 1:

The reviewer observed that there is a great partnership with LBNL for analysis and ANL CAMP facility for electrodes.

Reviewer 2:

The reviewer said collaboration was reasonable for a national laboratory R&D project.

Reviewer 3:

The reviewer remarked collaboration and coordination appear to be well managed, judging from the cohesive progression of the research. For future work, this project may benefit by reaching out to other outside collaborators in key areas (additives, temperature consequences over multiple time and spatial scales, and thermodynamics).

Question 4: *Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.*

Reviewer 1:

The reviewer pointed out that the final deliverables are 100 mAh, which is great, but the team will not likely see a gassing issue there. So, the PI might consider some other investigations to uncover gassing issues—often they do not show up until size is 5–10 Ah.

Reviewer 2:

The reviewer remarked the future work stated in this project will allow deeper insights into the origins of diminished Li-ion cell performance at lower temperatures, and provide a path toward mitigating technical obstacles. The reviewer noted a deficiency: not mentioned is the aspect of Li-ion cell survivability and aging at higher temperatures (e.g., 50°C).

Reviewer 3:

The reviewer noted that the GBL additive has been studied extensively in the past for use in Li-ion cells. However, the new diagnostic tools developed recently should enable the team to gain insights on the proposed effort to understand why GBL reduces charge transfer at the cathode. The reviewer said the team should also devote future effort to understand why FEC reduces charge transfer at low temperatures, especially at the anode.

Question 5: *Relevance—Does this project support the overall DOE objectives? Why or why not?*

Reviewer 1:

The reviewer said that improved LT performance is highly relevant especially as EVs become closer to wide-scale market adoption.

Reviewer 2:

The reviewer remarked weighing the collective responses expressed in earlier questions, this work supports DOE objectives for advancing the SOA for LT battery electrolytes, which if successful will help expand proliferation of LIB systems to greater geographical areas.

Reviewer 3:

The reviewer asserted that a good understanding of factors affecting LT performance is critical for achieving a wide temperature electrolyte.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The reviewer commented that a $2.35 million, 3-year effort should be sufficient to achieve a good understanding of the LT issue and provide mitigations.

Reviewer 2:

The reviewer remarked resources are sufficient given the nature of the team, the objectives, collaborations, and schedule.

Reviewer 3:

The reviewer saw no issues with resources.

Presentation Number: bat522
Presentation Title: Thin-film Lithium Metal Manufacture by Room Temperature Electrodeposition
Principal Investigator: Alirio Liscano (Albemarle)

Presenter

Alirio Liscano, Albemarle

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers felt that the project was relevant to current DOE objectives, 0% of reviewers felt that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers felt that the resources were sufficient, 0% of reviewers felt that the resources were insufficient, 0% of reviewers felt that the resources were excessive, and 0% of reviewers did not indicate an answer.

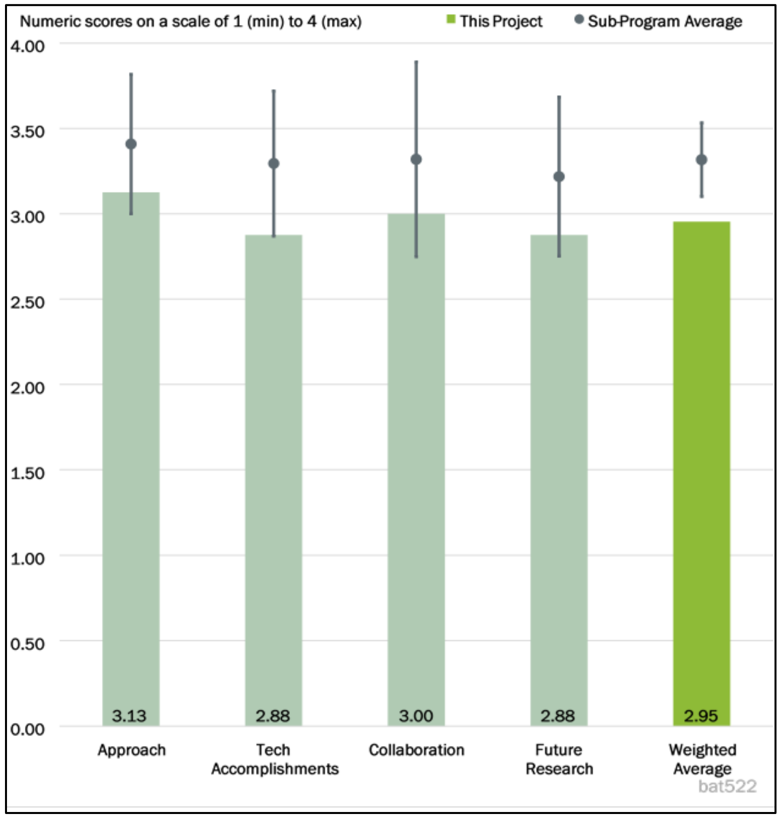


Figure 2-73 - Presentation Number: bat522 Presentation Title: Thin-film Lithium Metal Manufacture by Room Temperature Electrodeposition Principal Investigator: Alirio Liscano (Albemarle)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed and well-planned.

Reviewer 1:

The reviewer said the team conducted room-temperature electrodeposition method to produce thin-film Li metal, and the membrane and the device are optimized to improve the performance, safety, and cost-effectiveness. The approach is good, according to the reviewer.

Reviewer 2:

The reviewer said there are multiple critical components to this project. The stated target of this report is the development of electrochemically plated Li-metal anode structures as a low-cost alternative to commercially produced foil versions. This appears to be well thought out and a reasonable objective. The larger scope of this project involves a target cell design that uses a specialty membrane to provide essentially a two-compartment design. The reviewer noted water-based Li salts are a target for the anode side and non-aqueous based electrolyte systems for the cathode side. While the latter is probably the major gating item to the success of this approach, there is very little technical detail associated with this component as opposed to the Li-metal structure.

Reviewer 3:

The reviewer said the approach is clear and concise. Overall, the strategy is effective in depositing Li metal using a low-cost R2R method. While the barriers to the project were clearly stated, the poster could have quantified the amount of water crossover using the membrane. The reviewer said the presenter mentioned that the water was quantified using Coulometric titration, but it is difficult to determine if that concentration is "low" because no quantifiable information was provided. The second barrier was mentioned and clearly illustrated on the poster.

Reviewer 4:

The reviewer remarked the problem of generating Li metal from aqueous salt solutions is ambitious. It is unclear if a membrane that is selective for Li but not water can ever be made.

Question 2: Technical Accomplishments and Progress toward overall project goals—the degree to which progress has been made and plan is on schedule.

Reviewer 1:

The reviewer remarked out of the four milestones that were listed, the progress seems on a par with the timeline provided. The poster clearly showed that the electrodeposited Li outperforms the commercial Li. The cathode used was lithium cobalt oxide (LCO). It is known that the cathode and anode have crosstalk in the cell. This may influence the overarching performance. To make a fair comparison of the electrodeposited versus commercial Li, it would be best to test this with various commercialized cathodes to determine if the cycle life continues to be enhanced with the electrodeposited Li. The reviewer said it would also be great to move into using low-Co and Co-free materials because this would address geopolitical issues. In achieving performance measures for the Li anode, it may prove useful to cycle the cells at various C-rates. The milestone mentions that the battery capacity retention is equal or better than conventional foil after 50 cycles at C/5, but the data provided were cycled at 0.5C (or C/2). This is why it may be best to show the discharge capacity fading at different C-rates to illustrate the comparison.

Reviewer 2:

The accomplishments shown seem reasonable, but this reviewer was skeptical about accomplishment of the overall goal. It was difficult to decipher this submission, which seems to have a different format that is less readable compared to other submissions.

Reviewer 3:

The reviewer said the Li metal plating work appears to show promise. The concept of a high conductivity, low water crossover membrane is fairly opaque in this presentation. The technical progress of this component cannot really be evaluated in any depth.

Reviewer 4:

The reviewer commented the thickness of the electrodeposited Li metal is well controlled to be approximately 20 μm, while the surface is rough from the SEM image. As for electrochemical performance, the electrodeposited Li indeed shows a 50% longer cycle life compared with commercial Li; however, the cyclability (80% capacity retention for 30 cycles) still needs to be further improved.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said the PI shows clear collaboration with ANL and SolidPower, which are responsible for electrodeposition and battery manufacturing, respectively.

Reviewer 2:

The reviewer noted no issues.

Reviewer 3:

According to the reviewer, the presenter mentioned that there are ongoing active collaborations. Because the model system has now been developed, it is possible to further these collaborations with battery manufacturing. There was some concern regarding the thickness of the transport membrane. The presenter mentioned that the thickness was negligible. The reviewer stressed that further evidence from the collaborator would be useful to determine why that thickness does not matter. If Li-ion mobility is a challenge and the membrane thickness can promote or hinder the Li mobility, the thickness must have some properties or influences that make it negligible to the overall system. More collaborative thought could be used to rationalize this concept.

Reviewer 4:

The reviewer remarked the extent of collaboration between the participating institutions was reasonable, but difficult to quantify, based on the limited scope of the review document.

Question 4: Proposed Future Research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways. Note: if the project has ended, please state project ended.

Reviewer 1:

The reviewer commented the proposed future research is effectively planned, and related to the objectives and current technical accomplishments.

Reviewer 2:

The reviewer said the stated goals, particularly the development of a prototype, are good.

Reviewer 3:

The reviewer remarked the goals associated with the development of a low-water crossover membrane are broad and vague.

Reviewer 4:

The reviewer stated that one of the remaining challenges is associated with developing a strategy for handling potential water crossover after the membrane synthesis has been scaled up for the prototype. While this is one of the challenges, nothing in the future work is stated to address this. The water crossover can potentially have a detrimental role on the cycle life of the cell. This is a major challenge that needs to be addressed with an appropriate strategy, yet the strategy was not mentioned. The reviewer asked if the membrane the membrane will have to be modified. During improved membrane development, will it be determined that thickness does have an influence on the uniformity of the deposited Li metal? There are quite a few challenges to overcome before determining the quality of the prototype and the resulting coin and pouch cells.

Question 5: Relevance—Does this project support the overall DOE objectives? Why or why not?

Reviewer 1:

The reviewer said methods for producing Li-metal foils are highly relevant to overall DOE objectives.

Reviewer 2:

The reviewer remarked that Li-metal systems of all flavors are being evaluated as a potential next-generation successor to traditional Li-ion. All reasonable system proposals should be evaluated. The reviewer pointed out that this particular concept seems very challenging.

Reviewer 3:

The reviewer commented the work is in support of the DOE objectives. The work is innovative and does support advancement of energy research and environmental cleanliness. As previously mentioned, using commercialized low-Co based cathodes would be one method to further move into the ongoing directions of Co-free materials in battery applications.

Reviewer 4:

The reviewer said the project is about Li-metal production, which supports the overall DOE objectives.

Question 6: *Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?*

Reviewer 1:

The resources are sufficient for the project to achieve the milestones, according to the reviewer.

Reviewer 2:

The reviewer said resource allocation is reasonable, especially given the cost share.

Reviewer 3:

The reviewer saw no issues.

Reviewer 4:

The reviewer remarked it seems as though there are sufficient resources provided from DOE, the cost share from the company, and resources from collaborators to complete the project objectives.

Acronyms and Abbreviations

µm	Micron
3-D	Three-dimensional
AIMD	ab initio molecular dynamics
Al	Aluminum
ALD	Atomic layer deposition
AM	Active material
AMAT	Applied Materials
AMO	Advanced Manufacturing Office
ANL	Argonne National Laboratory
ARL	U.S. Army Research Laboratory
ASR	Area-specific resistance
ASSB	All-solid-state-battery
BN	Butyronitrile
BNL	Brookhaven National Laboratory
BR	Battery Resourcers
BTMS	Behind-the-meter storage
BTO	Building Technologies Office
BY	Budget year
BYU	Brigham Young University
CAMP	Cell Analysis, Modeling, and Prototyping
CAMP	Cell Analysis, Modeling, and Prototyping Facility
CB	Carbon black
CCD	Critical current density
CE	Coulombic efficiency
CEI	Cathode-electrolyte interface
CFM	Complex framework materials
cm	Centimeter
CNF	Carbon nanofiber
Co	Cobalt
CO_2	Carbon dioxide
COVID-19	Coronavirus disease 2019

Cu	Copper
CV	Cyclic voltammetry
DCFC	Direct-current fast charging
DCIR	Direct current internal resistance
DMBQ	Dimethoxy benzoquinone
DOE	U.S. Department of Energy
DOL	Dioxolane
DRX	Cation-disordered rock salt
E_a	Activation energy
EAM	Electrochemically active mono-layers
EC	Ethylene carbonate
EERE	Office of Energy Efficiency and Renewable Energy
EMC	Ethyl methyl carbonate
EOL	End of life
EV	Electric vehicle
FCE	First-cycle efficiency
FCTO	Fuel Cell Technologies Office
FEC	Fluoroethylene carbonate
FSP	Flame Spray Pyrolysis
FTIR	Fourier-transform infrared spectroscopy
FY	Fiscal Year
g	gram
GBL	gamma butyrolactone
GED	Gravimetric energy density
GHG	Greenhouse gas
GM	General Motors
GSE	Glassy solid electrolyte
HE	High energy
HFTO	Hydrogen and Fuel Cell Technologies Office
HOPG	Highly oriented pyrolytic graphite
HPPC	Hybrid pulse power characterization
HT	High-temperature

HVM	High volume manufacturing
ID	Identification
IL	Ionic liquid
In	Indium
INL	Idaho National Laboratory
IP	Intellectual property
IUPUI	Indiana University – Purdue University Indianapolis
IZ	Isoxazol
Kg	Kilogram
KIT	Karlsruhe Institute of Technology
KPI	Key performance indicator
kWh	Kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LCA	Life-cycle analysis
LCO	Lithium cobalt oxide
LFP	Lithium iron phosphate
LHCE	Localized high-concentration electrolyte
Li	Lithium
$Li_7La_3Zr_2O_{12}$	Lithium lanthanum zirconium oxide
LIB	Lithium-ion battery
LIBRA	Lithium Ion Battery Resource Assessment
LIC	Lithium-ion conducing
LiF	Lithium fluoride
LiFSI	Lithium bis(fluorosulfonyl)imide
LiNO3	Lithium nitrate
Li-SIA	Lithium structurally isomorphic alloys
LLZO	Lithium lanthanum zirconium oxide
LMNO	Lithium manganese nickel oxide
LMO	Lithium manganese oxide
LNMC	Lithium nickel manganese cobalt oxide
LNMO	Lithium nickel manganese oxide
LNO	Lithium-nickel dioxide (LiNiO2)

LOE	Level of effort
LPF	Lithium plating free
LPS	Sulfide-based solid state electrolyte, Li_3PS_4
LPSCl	Halogenated sulfide-based solid state electrolyte
LT	Low-temperature
LTO	Lithium titanate (Li4Ti5O12)
M	Molar
mAh	Milliamp-hour
MD	Molecular dynamics
MERF	Materials Engineering Research Facility
mg	Milligram
MIC	Molecular ionic composite
MLPC	Multi-level porous carbon/multi-layer pouch cell
MS	Mass spectroscopy
MT	MegaTon
MW	Microwave
N/P	Negative-positive ratio
NASA	National Aeronautics and Space Administration
NCA	Nickel cobalt aluminum oxide
NCE	No-cost extension
NCM	Nickel cobalt manganese oxide
NECST	Nanomaterials for Energy Conversion Storage Technology
NF	Non-flammable
Ni	Nickel
NMC	Nickel manganese cobalt oxide
NMP	N-methyl-2-pyrrolidone
NREL	National Renewable Energy Laboratory
OE	Office of Electricity
OEM	Original equipment manufacturer
OIM	Organic insertion materials
ORNL	Oak Ridge National Laboratory
PAN	Polyacrylonitrile

PBI	Polybenzimidazole
PDF	Pair-distribution function
PEG	Polyethylene glycol
Penn State	Pennsylvania State University
PEO	Polyethylene oxide
pH	Power of hydrogen
PI	Principal Investigator
PNNL	Pacific Northwest National Laboratory
PS	Polysufide
PVDF	Polyvinylidene difluoride
Q	Quarter
R&D	Research and development
R2R	Roll to roll
RCT	Charge transfer resistance
S	Sulfur
S@PAN	Sulfurized polyacrylonitrile
S@PC	Sulfurized porous carbon
SEI	Solid-electrolyte interface
SEM	Scanning electron microscopy
SETO	Solar Energy Technologies Office
Si	Silicon
SIMS	Secondary Ion Mass Spectrometry
SiO_x	Oxides of silicon
SLAC	Stanford Linear Accelerator Center
SN	Succinonitrile
SNL	Sandia National Laboratories
SOA	State of the art
SOC	State of charge
SPAN	Sulfurized polyacrylonitrile
SSB	Solid-state battery
SSE	Solid-state electrolyte
SUNY	State University of New York

T	Temperature
TEM	Transmission electron microscopy
Ti	Titanium
ToF	Time-of-Flight
TVR	Taylor Vortex Reactor
TXM	Transmission X-ray microscopy
U.S.	United States
URI	University of Rhode Island
USABC	United States Advanced Battery Consortium
V	Volt
VTO	Vehicle Technologies Office
Wh	Watt-hour
wt.%	Weight percent
XANES	X-ray absorption near edge structure spectroscopy
XCEL	eXtreme Fast Charge Cell Evaluation of Lithium-ion Batteries
xEV	An electric vehicle, including battery electric vehicle (BEV), hybrid xEV electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), etc.
XFC	Extreme fast charging
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction
ZnO	Zinc oxide