2. Batteries R&D

The Vehicle Technologies Office (VTO) has a comprehensive portfolio of early-stage research to enable industry to accelerate the development and widespread use of a variety of promising sustainable transportation technologies. The research pathways focus on fuel diversification, vehicle efficiency, energy storage, and mobility energy productivity that can improve the overall energy efficiency and efficacy of the transportation or mobility system. VTO leverages the unique capabilities and world-class expertise of the National Laboratory system to develop innovations in electrification, including advanced battery technologies; advanced combustion engines and fuels, including co-optimized systems; advanced materials for lighter-weight vehicle structures; and energy efficient mobility systems. VTO is uniquely positioned to address early-stage challenges due to strategic public-private research partnerships with industry (e.g., U.S. DRIVE, 21st Century Truck Partnership) that leverage relevant expertise. These partnerships prevent duplication of effort, focus DOE research on critical R&D barriers, and accelerate progress. VTO focuses on research that industry does not have the technical capability to undertake on its own, usually due to a high degree of scientific or technical uncertainty, or that is too far from market realization to merit industry resources.

The Battery Technologies R&D (BAT) subprogram funds research programs with partners in academia, National Laboratories, and industry, focusing on generating knowledge of high-energy and high-power battery materials and battery systems that can support industry to significantly reduce the cost, weight, volume, and charge time of plug-in electric vehicle (PEV) batteries. Advanced Battery Materials Research focuses on early-stage research of new lithium-ion cathode, anode, and electrolyte materials, which currently account for 50%–70% of PEV battery cost. This work will be carried out through competitively selected, cost-shared projects, in addition to research conducted as part of the Lithium Battery Recycling Prize and National Laboratory-led Recycling Center launched in fiscal year 2019. Additionally, the subprogram will continue the Battery500 research consortium, which focuses on developing “beyond lithium-ion” technologies that have the potential to significantly reduce weight, volume, and cost by three times ($80/kWh). New research supports batteries and electrification in large trucks, which may require unique technology based on the charging patterns, daily usage, range, and overall length of vehicle life.

The Advanced Battery Cell R&D effort focuses on 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. This activity also supports high-fidelity battery performance, life, fast charging, and safety testing of innovative battery technologies at the National Laboratories and the lithium-ion battery recycling center.

The Behind the Meter Storage (BTMS) effort focuses on innovative solutions capable of mitigating potential grid impacts of PEV high-power charging systems, such as critical materials-free battery energy storage technologies. Solutions in the 1–10 MWh range will support optimal charging system design, eliminate potential grid impacts of high-power PEV charging systems, and lower installation costs and costs to the consumer. Efforts will include research and development of advanced power electronics and controls to assure seamless integration of energy storage, vehicle charging, and behind-the-meter power transmission.

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
bat049	Tailoring Integrated Layered- and Spinel-Electrode Structures for High-Capacity Lithium-Ion Cells	Jason Croy (ANL)	2-9	3.25	3.25	3.38	3.25	**3.27**
bat240	High-Energy Anode Material Development for Lithium-Ion Batteries	Cary Hayner (Sinode Systems/ NanoGraf)	2-13	3.00	2.90	3.40	2.80	**2.98**
bat247	Fast-Charge and Low-Cost Lithium Ion Batteries for Electric Vehicles	Herman Lopez (Zenlabs Energy, Inc./ Envia Systems)	2-18	3.20	3.30	3.20	3.20	**3.25**
bat251	Cathode Materials for Next Generation Lithium-Ion Batteries: Design, Synthesis, and Characterization of Low-Cobalt Cathodes	Jason Croy (ANL)	2-23	3.38	3.25	3.63	3.13	**3.31**
bat252	Cathode Materials for Next Generation Lithium-Ion Batteries: Diagnostic Testing and Evaluation of Low-Cobalt Cathodes	Dan Abraham (ANL)	2-27	3.63	3.38	3.50	3.38	**3.45**
bat253	Cathode Materials for Next Generation Lithium-Ion Batteries: Theory and Modeling of Low-Cobalt Cathodes	Hakim Iddir (ANL)	2-31	3.50	3.50	3.50	3.25	**3.47**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat293	A Closed-Loop Process for End-of-Life Electric Vehicle Lithium-Ion Batteries	Yan Wang (Worcester Polytechnic Institute)	2-35	3.20	3.20	3.40	3.20	**3.23**
bat332	High Electrode-Loading Electric Vehicle Cell	Mohamed Taggougui (24M Technologies)	2-39	3.10	3.20	3.20	3.33	**3.19**
bat355	Development of High-Performance Lithium-Ion Cell Technology for Electric Vehicle Applications	Madhuri Thakur (Farasis Energy)	2-43	3.20	3.20	3.50	3.00	**3.21**
bat356	Lithium-Ion Cell Manufacturing Using Directly Recycled Active Materials	Mike Slater (Farasis Energy)	2-47	3.30	3.00	3.00	3.10	**3.09**
bat357	Thicker Cathode Coatings for Lithium-Ion Electric Vehicle Batteries	Stuart Hellring (PPG Industries)	2-52	3.10	3.30	3.50	3.50	**3.30**
bat359	Status and Challenges of Electrode Materials for High-Energy Cells	Stanley Whittingham (Binghamton University)	2-57	3.50	3.50	3.67	3.50	**3.52**
bat360	Scale-Up Optimization and Characterization of High-Nickel Cathodes	Arumugam Manthiram (University of Texas at Austin)	2-60	3.50	3.50	3.50	3.33	**3.48**
bat361	Understanding Electrode Interface Through Cryogenic Electron Microscopy	Yi Cui (Stanford University/ SLAC)	2-63	3.67	3.50	3.83	3.50	**3.58**
bat362	Lithium-Metal Anodes: Problems and Multiple Solutions Based on Hosts, Interphase, and Electrolytes	Jason Zhang (PNNL)	2-66	3.50	3.67	3.67	3.33	**3.58**
bat364	Surface Coating for High-Energy Cathode	Jihui Yang (University of Washington)	2-69	3.17	2.83	3.33	3.00	**3.00**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat365	Stabilizing Lithium-Metal Anode by Interfacial Layer	Zhenan Bao (Stanford University/ SLAC)	2-72	3.20	3.40	3.50	3.20	**3.34**
bat366	Advanced Imaging and Quantitative Characterization of Lithium-Metal Anode and Its Solid Electrolyte Interphase (SEI)	Shirley Meng (University of California at San Diego)	2-77	3.50	3.67	3.67	3.17	**3.56**
bat367	Characterization Studies on Li-Metal Anode and High-Ni Cathode Materials	Peter Khalifah (BNL)	2-80	3.50	3.50	3.50	3.50	**3.50**
bat368	Battery500 Integrated Cell Diagnostics and Modeling to Identify Critical Gaps in Achieving High Cycle Life	Eric Dufek (INL)	2-82	3.17	3.33	3.83	3.17	**3.33**
bat369	High-Energy Rechargeable Lithium-Metal Cells: Fabrication and Integration	Jie Xiao (PNNL)	2-85	3.70	3.60	3.50	3.20	**3.56**
bat370	Advanced Diagnostics of Nickel-Rich, Layered-Oxide Secondary Particles	Mike Toney (Stanford University/ SLAC)	2-89	3.50	3.60	3.40	3.50	**3.54**
bat376	Disordered Rocksalt Transition-Metal Oxides (TMOs): Recent Advances	Gerbrand Ceder (LBNL)	2-93	3.50	3.38	3.50	3.25	**3.41**
bat388	Silicon Deep Dive: Update and Overview	Jack Vaughey (ANL)	2-97	3.50	3.40	3.50	3.20	**3.41**
bat392	Enabling Rapid Charging in Lithium-Ion Batteries via Integrated Acoustofluidics	James Friend (University of California at San Diego)	2-102	3.38	3.13	3.38	3.13	**3.22**
bat393	Development of an Extreme Fast-Charging Battery	Chao-Yang Wang (Penn State University)	2-106	3.38	3.38	3.50	3.25	**3.38**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat394	Highly Ordered Hierarchical Anodes for Extreme Fast-Charging Batteries	Neil Dasgupta (University of Michigan)	2-110	3.25	3.50	3.50	3.13	**3.39**
bat395	Developing Safe, High-Energy, Fast-Charge Batteries for Automobiles	Wenjuan Mattis (Microvast, Inc.)	2-114	3.00	3.00	3.00	3.17	**3.02**
bat396	Enabling Extreme Fast Charging through Anode Modification	Esther Takeuchi (Stony Brook University)	2-117	3.33	3.17	3.33	3.33	**3.25**
bat397	Titanium Niobium Oxide-Based Lithium-Ion Batteries for Extreme Fast-Charging Applications	Sheng Dai (University of Tennessee at Knoxville)	2-120	3.00	2.67	3.17	2.83	**2.83**
bat398	Extreme Fast-Charging Lithium-Ion Batteries	Edward Buiel (Edward Buiel Consulting, LLC)	2-124	2.83	2.67	2.50	3.00	**2.73**
bat400	Novel Liquid/Oligomer Hybrid Electrolyte with High Lithium-Ion Transference Number (Hi-LiT) for Extreme Fast Charging	Zhijia Du (ORNL)	2-127	3.33	3.00	3.33	3.00	**3.13**
bat401	Advanced Electrolytes for Extreme Fast Charging	William Chueh (Stanford University)	2-130	3.33	3.33	3.17	3.17	**3.29**
bat404	Direct Fluorination of Disordered Rock Salt Cathode Oxides : Synthesis and Characterization	Jagit Nanda (ORNL)	2-133	3.50	3.38	3.38	3.25	**3.39**
bat405	Advanced Microscopies of Next-Generation Lithium-Ion Battery Cathode Materials	Chongmin Wang (PNNL)	2-137	3.13	3.25	3.38	3.13	**3.22**
bat406	Disordered Rocksalt Transition-Metal Oxides (TMOs): Synthetic Strategies	Guoying Chen (LBNL)	2-140	3.38	3.25	3.25	3.13	**3.27**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat411	Aerosol Manufacturing Technology for Production of Low-Cobalt Lithium-Ion Battery Cathodes	Toivo Kodas (Cabot Corporation)	2-144	3.00	3.17	3.33	3.17	**3.15**
bat412	Novel Lithium-Iron and Aluminum Nickelate (NFA) as Advanced Cobalt-Free Cathode Materials	Ilias Belharouak (ORNL)	2-147	3.33	3.33	3.33	3.33	**3.33**
bat413	High-Performance, Low-Cobalt Cathode Materials for Lithium-Ion Batteries	Donghai Wang (Penn State University)	2-150	3.00	2.83	3.00	2.50	**2.85**
bat414	Enhancing Oxygen Stability in Low-Cobalt, Layered-Oxide Cathode Materials	Huolin Xin (University of California at Irvine)	2-153	3.63	3.63	3.63	3.38	**3.59**
bat415	High-Nickel Cathode Materials for High-Energy, Long-Life, Low-Cost Lithium-Ion Batteries	Arumugam Manthiram (University of Texas at Austin)	2-157	3.67	3.50	3.50	3.33	**3.52**
bat416	Cobalt-Free Cathode Materials and Their Novel Architectures	Shirley Meng (University of California at San Diego)	2-160	3.50	3.50	3.63	3.25	**3.48**
bat417	Cobalt-Free Cathodes for Next-Generation Lithium-Ion Batteries	Neil Kidner (Nexceris)	2-163	3.00	2.67	2.83	2.83	**2.79**
bat436	Silicon Electrolyte Interface Stabilization (SEISTA): Update and Overview	Tony Burrell (NREL)	2-166	3.50	3.60	3.60	3.10	**3.51**
bat437	Silicon Electrolyte Interface Stabilization (SEISTA): Electrochemical Methods	Robert Kostecki (LBNL)	2-171	3.60	3.30	3.50	3.20	**3.39**
bat438	Silicon Electrolyte Interface Stabilization (SEISTA): Advanced Characterization	Glen Teeter (NREL)	2-175	3.40	3.20	3.50	3.20	**3.29**
bat439	Silicon Deep Dive: Silicon-Based Slurries and Electrodes	Beth Armstrong (ORNL)	2-179	3.70	3.40	3.50	3.20	**3.46**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat440	Silicon Deep Dive: Silicon Functionalization	Zhengcheng Zhang (ANL)	2-183	3.50	3.38	3.50	3.13	**3.39**
bat441	High-Performance Electrolyte for Lithium-Nickel-Manganese Oxide (LNMO)/Lithium-Titanate (LTO) Batteries	Jennifer Hoffman (Gotion)	2-187	3.30	3.00	3.20	3.00	**3.10**
bat442	Behind-the-Meter-Storage (BTMS) Overview	Anthony Burrell (NREL)	2-192	3.00	2.25	3.00	2.00	**2.50**
bat444	Highly Loaded Sulfur Cathode, Coated Separator, and Gel Electrolyte for High-Rate Lithium-Sulfur Battery	Yong Joo (Cornell University)	2-195	3.40	3.20	3.50	3.30	**3.30**
bat445	Multifunctional Lithium-Ion Conducting Interfacial Materials for Lithium-Metal Batteries	Donghai Wang (Penn State University)	2-200	3.50	4.00	3.33	3.50	**3.73**
bat446	Electrochemically Stable, High-Energy Density Lithium-Sulfur Batteries	Prashant Kumta (University of Pittsburgh)	2-203	3.50	3.50	3.50	3.17	**3.46**
bat447	3-D Printed, Low-Tortuosity Garnet Framework for Beyond 500 Wh/kg Batteries	Eric Wachsman (University of Maryland)	2-206	3.17	3.17	3.33	3.33	**3.21**
bat448	Advanced Electrolyte Supporting 500 Wh/kg Lithium-Carbon/Nickel Manganese Cobalt (NMC) Batteries	Chunsheng Wang (University of Maryland)	2-209	3.60	3.80	3.40	3.50	**3.66**
bat449	Controlled Interfacial Phenomena for Extended Battery Life	Perla Balbuena (Texas A&M)	2-214	3.50	3.00	3.33	3.17	**3.19**
bat450	Design, Processing, and Integration of Pouch-Format Cell for High-Energy Lithium-Sulfur Batteries	Mei Cai (General Motors)	2-218	3.67	3.50	3.67	3.67	**3.58**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
bat451	Solvent-Free and Non-Sintered 500 Wh/kg All Solid-State Battery	Mike Wixom (Navitas Advanced Solutions Group)	2-221	3.17	2.50	3.50	3.33	**2.90**
bat452	High-Energy Solid-State Lithium Batteries with Organic Cathode Materials	Yan Yao (University of Houston)	2-224	3.25	3.13	3.38	3.25	**3.20**
bat453	Composite Cathode Architectures Made by Freeze-Casting for All Solid-State Lithium Batteries	Marca Doeff (LBNL)	2-228	3.50	3.50	3.50	3.50	**3.50**
bat454	Development of Long-Life Lithium/Sulfur-Containing Polyacrylonitrile Cells	Ping Liu (University of California at San Diego)	2-231	3.83	3.50	3.83	3.50	**3.63**
bat455	In Operando Characterization of Lithium Plating and Stripping	William Chueh (Stanford University)	2-235	3.50	3.33	3.50	2.83	**3.33**
Overall Average				**3.36**	**3.29**	**3.41**	**3.20**	**3.31**

Presentation Number: bat049
Presentation Title: Tailoring Integrated Layered- and Spinel-Electrode Structures for High-Capacity Lithium-Ion Cells
Principal Investigator: Jason Croy (Argonne National Laboratory)

Presenter

Jason Croy, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

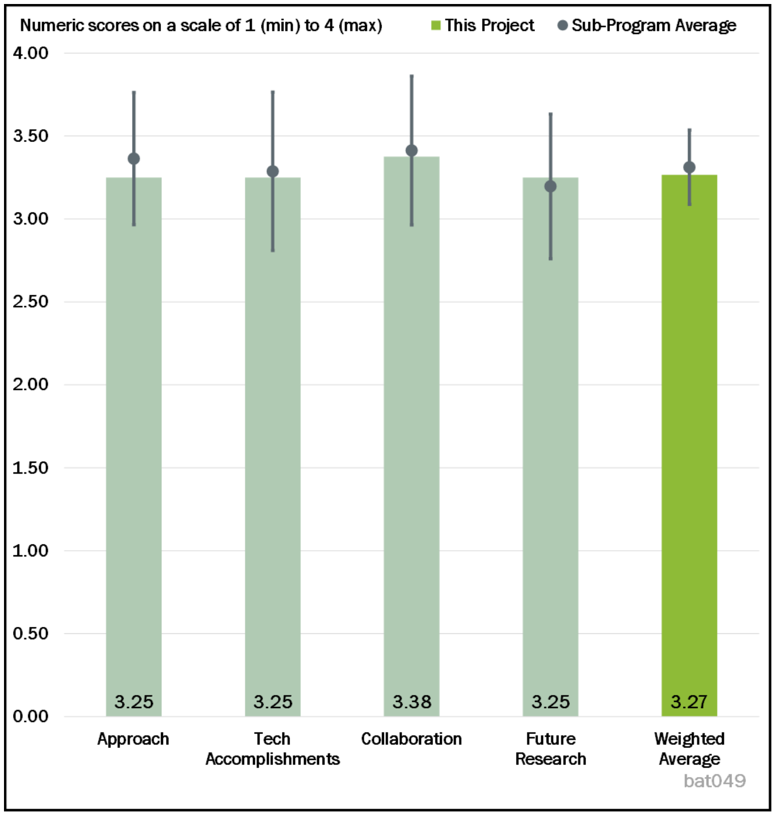

Figure 2-1 - Presentation Number: bat049 Presentation Title: Tailoring Integrated Layered- and Spinel-Electrode Structures for High-Capacity Lithium-Ion Cells Principal Investigator: Jason Croy (Argonne National Laboratory)

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:

This work showed very promising results with the manganese (Mn)-rich layered-layered-spinel (LLS) cathode. The precipitation parameters were very interesting and resulted in single crystals of manganese carbonate ($MnCO_3$) precursor. It would be interesting if, in the future, those cathode particles show electrochemical advantages versus standard powders. The reviewer found the results presented by the team for cathode powders with no cobalt (Co) content to be very exciting.

Reviewer 2:

There is lot of value in developing better understanding of the relationships between synthesis parameters and cathode particles. Designing robust surfaces also has a potential to address some of the key challenges.

Reviewer 3:

In the last year, the team has identified a critical point to develop the novel layered-layered-spinel lithium (Li), Mn-rich oxides using facile co-precipitation. The idea to use slight adjustments of calcination temperature is a good approach to produce samples with significantly different properties and performance to understand its mechanisms.

Reviewer 4:

Some interesting results are shown, but it was not clear to the reviewer how scientific information from one area is informing the work in another.

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:
In the last year, the team unraveled the trend of higher calcination temperatures resulting in large primary particles, smaller surface area, limited diffusivity, and less favorable electrochemistry. An atomic-layer deposition (ALD)-coated lithium-fluoride (LiF) layer was used to confirm the improvement of cyclic performance. Also, some preliminary results of morphology control of $MnCO_3$ precursors and low-temperature spinel zero-strain cathodes are interesting findings.

The reviewer recommended two areas for further elaboration and asked why such a narrow range of temperature change (925°-1,000° Celsius [C]) can introduce such a big difference. It would be helpful to provide more supporting data to investigate structural information, such as high-resolution scanning transmission electron microscopy for the long-range and short-range ordering. It would be interesting to know if there is any significant oxygen release in Cycle 1 for the LLS cathode when charging up to 4.6 volts (V). If so, the role of a LiF coating to suppress the gas release can be discussed.

Reviewer 2:
The reviewer commented that the lithiation experiments that resulted in different surface-area powders are very interesting. It could be of interest to see if the higher surface-area powders obtained at lower processing temperatures are better powders for high-power applications. The generation of cubic and rhombohedral structures of cathode material obtained by modifying the Mn concentration is something that can improved in the future. It was not clear to the reviewer how less spherical particles can overcome the lower tap density that those powders will show; in a practical application, the overall capacity of electrodes fabricated using those powders will be decreased. Spherical particles are the particles of choice in practical applications. How can the team bypass that issue?

Reviewer 3:
This project in part focused on the Mn-rich cathode and studied the effect of calcination temperature. Time for calcination was not provided. In fact, one should look at the temperature-time trajectory for each calcination. It was interesting that the team observed an interesting variation in the properties in a narrow temperature range. What are the scientific rationales for the observed behavior?

Reviewer 4:
The reviewer noted that progress was made and useful insight was generated on the impact of synthesis conditions, lithiation, surface treatment, and other approaches on cathode properties.

Some of the observed effects have opposing impacts. For example, higher calcination temperature reduces surface area, but it also seems to negatively impact discharge capacity. It would be useful to clarify if there is a path to optimize synthesis and other conditions in such a way to prevent or minimize tradeoffs. This was not clear from the presentation and work to date.

Small changes to synthesis conditions can result in large changes in properties and performance. This can be a concern for practical application of proposed approaches.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Collaboration and coordination among Argonne National Laboratory (ANL), University of Illinois at Chicago, and universities seems to be excellent.

Reviewer 2:
Collaboration seems to be working well. Electron microscopy, X-ray analysis, stability analysis, synthetic efforts, and electrochemical measurements are well coordinated, according to the reviewer.

Reviewer 3:
The team collaboration looks good.

Reviewer 4:
In the last year, the team has indicated the close collaboration within various teams at ANL. The reviewer observed that the external collaboration outside ANL could be considered as well, if needed.

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:
According to the reviewer, the project team proposed a reasonable plan of next-year actions. It is interesting to see more results of the application of online electrochemical mass spectroscopy (OEMS) and the further scale-up confirmation of low-temperature (LT)-spinel zero-strain cathodes with the electrochemistry incorporated in a solid-state battery cell.

Reviewer 2:
Future experiments probably may need to show some electrochemical data from the cubic and rhombohedral particles. Furthermore, by using dilute Mn solutions during synthesis, the process will generate less cathode material per unit of time. Maybe that can be countered by decreasing the residence time for this precipitation reaction. Maybe residence time is one of the variables that the project team may want to explore. The particle shape or sphericity of the particles is also dictated by the stirring power. That could be an additional precipitation variable that the team may want to explore.

Reviewer 3:
The reviewer said that this is an extension of the current work.

Reviewer 4:
The focus of integrated structures seemed adequate to the reviewer, who commented that designing more robust surfaces and using gas analysis should reveal more details.

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

Reviewer 1:
Yes, this project supports the overall U.S. Department of Energy (DOE) objectives of decreasing Co content in cathode materials to lower the cost of the battery without decreasing the electrode performance. Experimental data clearly showed the production of such powders with promising electrochemical data.

Reviewer 2:
The reviewer stated that the project supports the overall DOE objectives. This study is focusing on the understanding of a new type of Li-rich cathode having comparable electrochemistry compared to conventional nickel manganese cobalt oxide (NMC) but with lower cost and higher stability. This understanding is favorable for next-generation electric vehicle (EV) applications.

Reviewer 3:
A Mn-rich cathode has the potential provide a cheaper and safer cathode.

Reviewer 4:
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:
This project has achieved the designated milestones on time so far with the sufficient resources.

Reviewer 2:
The team has needed resources in place.

Reviewer 3:
Resources seemed sufficient to the reviewer.

Reviewer 4:
At this stage the resources may be sufficient. However, at some point, the project team may want to scale up the precipitation process. In that case they will need additional support.

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

Presenter

Cary Hayner, NanoGraf

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

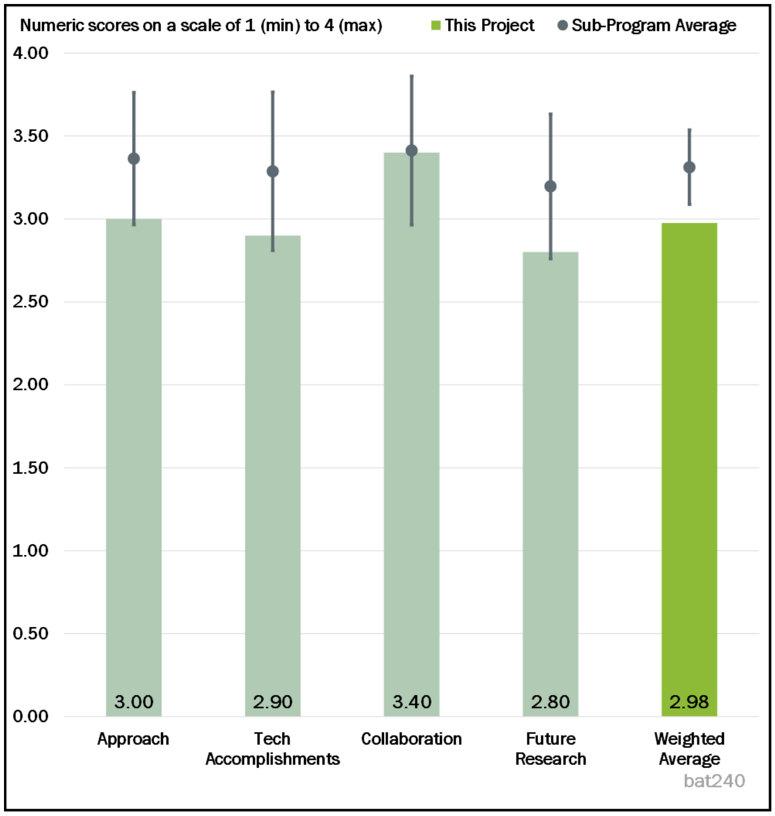

Figure 2-2 - Presentation Number: bat240 Presentation Title: High-Energy Anode Material Development for Lithium-Ion Batteries Principal Investigator: Cary Hayner (NanoGraf)

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:

Researchers addressed the barriers very well by demonstrating increased energy density and specific energy in improving battery life performances. The reviewer also liked the parallel path approach in addressing the battery- life performance issues.

Reviewer 2:

Nanograf is developing high-energy, Si-based anodes for lithium-ion batteries (LIBs). The major approaches include graphenic wrapping and surface coating. While the project was just started last year, the company has made some modest progress. One of the potential issues about the approach is the cost of graphene.

Reviewer 3:

The company's approach to producing a Si-based material for Li-ion cells is to coat the material with graphene, which is interesting. Its approach to making improvements was not so clear to the reviewer.

Reviewer 4:

For cells using significant amounts of Si, the swelling of the cell must be addressed. This appears to be completely missing from the approach. The reviewer suggested that the project team please measure the reversible volume change during one charge-and-discharge cycle and the irreversible volume change after many cycles. Additionally, the heat generated with respect to the silicon hysteresis could also be important for fast charging. The reviewer asked the team to please measure this contribution.

Reviewer 5:
The project was designed by Nanograf, which is aiming to be a component manufacturer of anode powders, but the barriers being addressed are perhaps better addressed by a battery manufacturer, which Nanograf says they are not interested in becoming. So, as noted in the presentation, Nanograf is trying to accomplish "technology push" and provide the full-cell research and development (surface treatments, electrolyte additives, binders, cell balancing, etc.) to demonstrate the value proposition of their graphene-wrapped Si-anode material.

It was not clear to the reviewer how the project is designed to incorporate the help of A123 in these tasks. For example, is A123 helping with finding new electrolyte additives to form stable solid-electrolyte interphases (SEIs)? Although they probably could use more explicit help from A123, it is clearer how the performance and lifetime barriers are being addressed by Nanograf, but it was not clear how the cost targets are being addressed. There was no goal stated (i.e., a % decrease in cost of what?), and there was only a brief mention that cost is being considered. How are cost factors affecting the optimization of the anode materials to meet technical performance goals? Surely cost is being considered, but it was not clear how the project is specifically designed to achieve cost targets.

Given that performance still has a long way to go to meet the targets and there are clearly many competing factors in the performance, the project could also benefit from a more explicit role for post-mortem testing to determine the failure mechanisms and guide mitigation strategies. Having this type of work just in the background will likely hinder progress eventually.

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 25% increase in life cycle from the previous year is very good path forward. Researchers also addressed the logistics footprint by improving manufacturing, supply chain, and sourcing for all commercial application; if implemented, this will be very useful.

Reviewer 2:
In quarter (Q) 1 of 2020, the project team achieved a cycle life of 320 with 80% capacity retention for their microstructural, treated graphene-wrapped silicon oxides (SiO_x) material. They also delivered 18, 1-amp-hour (Ah) cells for testing.

Reviewer 3:
The project team showed that it can get 200 cycles with SiO_x and graphene and 300 cycles with a mixture of SiO_x and graphite. Then the team performed a "microstructural treatment" to the SiO_x + graphene and increased the cycles to 288. The reviewer commented that there is no indication of what this is. With continual modifications of microstructural treatment, the team further improved the cycle life and the first-cycle coulombic efficiency (CE). With new surface treatments, the team can improve the first-cycle efficiency (FCE) and the capacity fade, but there was no explanation.

When the wrapping quality of the graphene is good, the results show low resistance of the electrode and good cyclability. With an improved electrolyte formulation, the team increased the cycle life to 350 cycles. Working with PPG, the team discovered a binder that does not require N-methyl-2-pyrrolidone (NMP) and only requires 2 weight percent (wt. %) with good adhesion. Work in material scale-up allows them to produce 80 kilograms (kg) per month and nearly the same capacity retention. These results are good, but there is no information as to how the team is making progress and so it was difficult for the reviewer to see how there will be further progress.

Reviewer 4:
This Si system appears to be at a very low technology readiness level (TRL). It is also not obvious to the reviewer that progress will be made during this project to raise it to a TRL.

Reviewer 5:
The project appears to be making some progress and has produced the first round of test cells for independent testing basically on schedule, but it was less clear to the reviewer that real progress against the performance indicators has been made. The performance improvements seem very incremental and not integrated; that is, FCE is improved in some data, but incremental gains in capacity retention seem to be lost.

Incremental gains in cycle life are achieved, but the materials have FCEs of only 66%. There is still a long way to go to reach 1,000 cycles and FCE of 85% at high energy density, and incremental improvements are not likely to be sufficient to reach the goals in another 2 years.

While the reviewer welcomed improvement in cycle life, the data suggest that there is a serious degradation mechanism limiting performance: the capacity retention generally falls quickly to 90% in the first 40 cycles, and the improvements only slow down the remaining degradation to 80% and incrementally improve cycle life. As suggested in the response to a reviewer's question, the company believes that the loss in capacity is due to Li inventory loss from SEI formation/re-formation, not from loss of electrical connectivity. However, the graphene innovation that the company is promoting is to solve the latter, which does not seem to be the problem.

So, Nanograf seems to be assuming the role of battery manufacturer after all and is trying to solve system-level problems that are general to Si-anode materials and not well addressed by their particular innovation—at least that is how it appears from the materials presented. On the positive side, the introduction of quality control processes and the increase in anode material production are both important improvements.

It was not clear to the reviewer how helpful the increase in peel strength for a cathode binder is for the project. What barrier to Si-anode usage in EVs does that address? Does it maybe address cost?

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Working with PPG and A123 helps to eliminate some of the bottlenecks in terms of materials supply and material characterization and also improves the research speed.

Reviewer 2:
Nanograf has involved several other companies with great and unique capabilities.

Reviewer 3:
It looked to the reviewer like close collaboration between project partners.

Reviewer 4:
The company collaborates with A123 and PPG, both industrial companies. Nanograf should be encouraged to find collaborators in National Laboratories and universities for more advanced testing techniques.

Reviewer 5:
The coordination of the effort across the partner set seems to be adequate although it was not clear to the reviewer who will do the safety and abuse testing that is mentioned. Again, collaboration could be better, or at least presented better. How much collaborative help is A123 providing in what appears to have become full-cell optimization, not just anode modification studies?

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:
There is a good path forward as the project team has identified a research approach to increase cycle efficiency, active materials, and also several associated variables to enhance further research.

Reviewer 2:
The plan for future research is focused on the right things. As expected, it is likely that the first cells being tested by ANL will show 400 or so cycles. So, the question is where to go to get the necessary improvements? The plan covers the basics and has a couple more decision points for the later test cells. It is not clear what happens if the second set of test cells comes back with only 450 cycles or comes back with the desired 600 cycles but very low FCE.

Is there really going to be a significant effort in looking at different formats: pouch, cylindrical, prismatic? The plan for the future might benefit from thinking now about what to do if it becomes apparent that incremental progress will not get the project to its goals in the remaining project time.

Reviewer 3:
The company's current technology has not yet reached the DOE and U.S. Advanced Battery Consortium (USABC) 2025 goals. They also need to get an assessment of the long-term cost for scale-up manufacturing.

Reviewer 4:
The reviewer noted that future plans are essentially to make everything better.

Reviewer 5:
There is no clear path to reach the project objectives.

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

Reviewer 1:
The project is well aligned with DOE objectives by attempting to answer the key questions about whether or not Si anodes are a viable solution for the EV market and are able to compete with graphite on performance and cost targets. Reaching the project goals would go a long way in answering those questions and have significant impact on the DOE objectives for vehicle electrification.

Reviewer 2:
The reviewer stated that the proposed research fits the DOE objectives and mission needs.

Reviewer 3:
A Si-based anode for LIBs is currently a major focus for achieving the targeted battery performance for electric vehicles.

Reviewer 4:
This supports DOE's objectives of improving the energy density of cells to reduce cost and extend range.

Reviewer 5:
High amounts of Si are unlikely to simultaneously achieve DOE's goal of low cost and fast-charge capability.

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

Reviewer 1:
At this point in the project, the resources available to the project appear to be sufficient to complete the research and development plan as proposed. There is no guarantee that the final milestones will be achieved, but the project has not suffered any costly setbacks yet that would make reaching the goals impossible. Cost and schedule for the project seem to be on track at the one-third point in the project.

Reviewer 2:
The researchers have sufficient and necessary resources to carry out the research.

Reviewer 3:
The project team is doing well in keeping track on their milestones.

Reviewer 4:
The resources are reasonable.

Reviewer 5:
The resources are sufficient.

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

Presenter

Herman Lopez, Zenlabs Energy

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

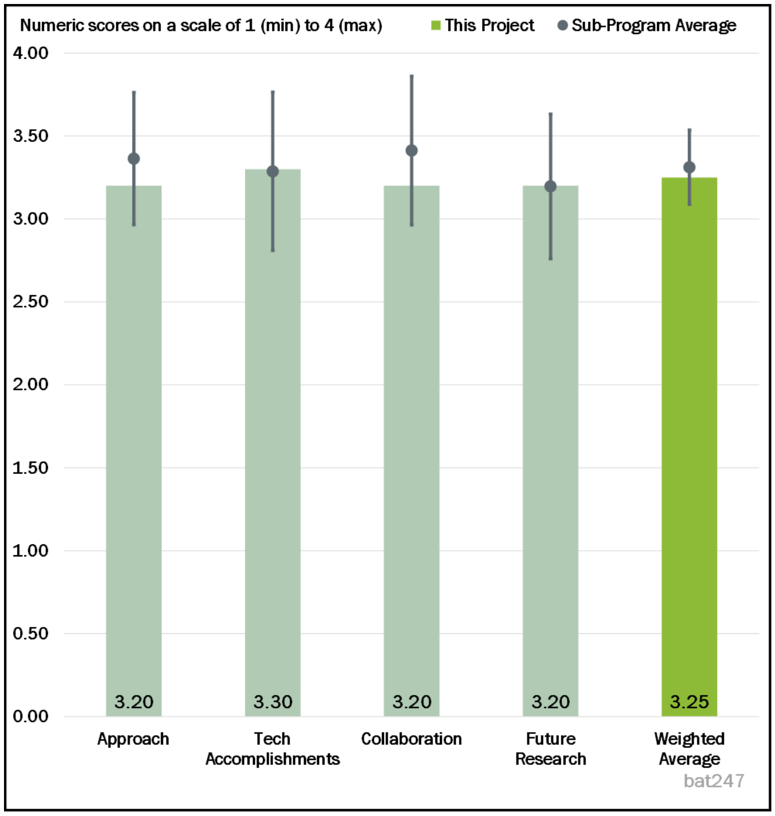

Figure 2-3 - Presentation Number: bat247 Presentation Title: Fast-Charge and Low-Cost Lithium Ion Batteries for Electric Vehicles Principal Investigator: Herman Lopez (Zenlabs Energy)

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:

Researchers have developed a nice flow chart on the cell development strategy and clearly identified upfront the barriers for fast-charge performance, which were addressed sufficiently.

Reviewer 2:

The project is very well planned and comprehensive and is clearly focused strongly on the technical barriers for fast charge and cycle/calendar life. While it can be assumed that the team is addressing the cost barriers in its work to evaluate and downselect electrolyte additives, solvents, salts and various electrode materials, it was not clear from the poster how the USABC 2023 cost targets are being addressed. It would have been helpful to the reviewer to have some idea how much cost reduction (%) was being targeted or required for the different components or at least some sense of the combined progress on cost that is needed from the baseline or cell build (CB) 1 design. The rest of the plan is crisply focused on overcoming the barriers to fast charge (FC), but the approach to reaching low cost is not so apparent. Overall, the plan to improve the technical performance of the cells is excellent and very comprehensive.

The development of pre-lithiation processes is depicted on Slide 5 as being "parallel" to the other optimization work, which is a bit of a risk, but it appears that some data on pre-lithiation approaches in the leading pouch-cell candidates will be available as early as CB 2, which is probably okay. All of the work appears to be feasible; the substantial progress to date at the halfway point of the project supports that conclusion.

Reviewer 3:
Zenlabs is trying to make low-cost, fast-charging batteries with targeted cycle and calendar life by developing novel electrolyte formulations and optimizing cell design. The selection of a high-nickel (Ni) NMC cathode and SiO_x anode is currently the mainstream route for LIB development.

Reviewer 4:
Zenlabs is starting from a cell chemistry where they achieve 310 milliamp-hour (mAh)/gram (g) and can achieve 1,000 cycles at C/1 charge and discharge. The goal is to meet the other USABC goals of 350 Watt-hours/kilogram (Wh/kg), good high- and low-temperature performance, and fast charge. The company also wants to deal with the gassing of Si-based cells and prelithiation and has set quite a few goals for itself. Most of the research is trial and error. There does not appear to be much chemical analysis to understand why one electrolyte is providing more functionality than another.

Reviewer 5:
For cells using significant amounts of Si, the swelling of the cell must be addressed. This appears to be completely missing from the approach. The reviewer suggested that the project team please measure the reversible volume change during one charge and discharge cycle along with the irreversible volume change after many cycles. Additionally, the heat generated with respect to the silicon hysteresis could also be important for fast charging; please measure this contribution.

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:
While it is still possible that the project’s goals will not be reached, the progress to date is excellent. The baseline cell design and materials were demonstrated at 1C/1C cycling at high capacity (310 Wh/kg at C/3) and cycle life of 1,000 cycles. The corresponding CB 1 reached nearly 700 cycles in fast-charging (4C/1C) testing, and the coin cell data for several new formulations and combinations look very promising to improve upon those results in the upcoming CB 2. If the CB 2 cells do not reach the 1,000-cycle goal for fast charge, they will probably be very close.

There is still a risk that gassing might be a problem—less progress on that concern was apparent from the results so far—but the project appears to be in very good shape and on track. The cell reproducibility data were also noteworthy, suggesting that the manufacturing process for the high-Ah pouch cells is being well controlled. The progress to date strongly suggests that 40-50 Ah pouch cells will very likely be possible for the second half of the project.

Reviewer 2:
The reviewer commented that target metrics are very well identified, and research performance is measured against the target clearly.

Reviewer 3:
At about halfway into the project duration, the project team has made impressive progress. It has achieved 1,000 cycles with 80% capacity retention with an 11.7-Ah pouch cell at 1C charge/discharge rate and more than 600 cycles at 4C rate. They have delivered 34, 12-Ah pouch cells to be tested at National Laboratories.

Reviewer 4:
The cell performance with regards to cyclability and fast-charge capability is respectable. However, the classic challenges associated with electrolyte stability remain. It was also not clear to the reviewer if the prelithiation approach simply enables the project to “run out the clock” by cycling quickly and thereby avoiding calendar-life problems.

Reviewer 5:

The project team is able to achieve 1,000 cycles at 1C charge/discharge cycles, 600 fast-charge cycles, and over 1,000 dynamic stress test (DST) cycles. It appears they will achieve less than 3 years of calendar life. The team has investigated a handful of electrolyte formulations to get to this point. The reviewer did not see much on prelithiation or on temperature stability. The team is also developing the ability to deliver large cells as a final deliverable and is able to demonstrate reasonable reproducibility. The reviewer did not see a path for drastically improving calendar life.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

Collaborating with Idaho National Laboratory (INL), Sandia National Laboratories (SNL), and the National Renewable Energy Laboratory (NREL) for testing of the cells will speed up the development process and also provides opportunities to hone in the subject-matter experts from the respective National Laboratories.

Reviewer 2:

The project is designed so that the National Laboratory partners are tasked with conducting tests and evaluation of performance. As long as the test cells are produced and delivered on time, there is not much else needed to coordinate the effort across the project team. But so far, the reviewer commented, the coordination and hand-off of test cells appears to be working well. It is also reasonable to assume that the National Laboratories will collaborate with Zenlabs on the interpretation of the test data, not just hand it over after the tests are complete.

Reviewer 3:

As an industrial company, Zenlabs has collaborations with three National Laboratories, a good combination for synergistic effects.

Reviewer 4:

Although the company does not mention it, it has lots of suppliers for electrolytes, SiO_x, and cathode materials.

Reviewer 5:

The reviewer was looking forward to seeing the contributions with regards to the work of SNL and NREL. Nothing was shown in this 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:

Future research is well aligned to address the gaps in the existing the development process, according to the reviewer.

Reviewer 2:

The future research proposed is to the point and feasible, especially because the project team is trying to understand the reaction mechanism to guide the identification of the electrolyte formulations, the electrode materials, and cell design.

Reviewer 3:

The plan is to continue screening and down-selecting materials the project team receives from suppliers.

Reviewer 4:

The proposed future research is probably well focused on the remaining challenges: calendar-life improvement, an effective pre-lithiation process, reduced gassing, continued electrolyte and electrode optimization, and large pouch-cell manufacturing. The latter two issues will likely require less attention than the first three issues.

Progress so far suggests that further improvement in cycle life under fast charge (6C perhaps instead of 4C?) and large pouch-cell manufacturing will be realized in CB 2 and CB 3. The priorities for the other three were not suggested. Which of these is the most challenging and will need the most resources? The calendar-life issue may be more difficult than expected. If, as suspected, it relates to SEI formation, this degradation mechanism may depend on the state of charge (SOC) at which the cell is aged.

Given that there could be lots of possibilities to explore and very limited opportunity to test theories and improvements (given the long test cycle required), a clearer plan on the approach to addressing calendar life would have been helpful. Gassing is another possible headache; it was not really clear to the reviewer where the team is in terms of this issue and therefore how much of the future work might have to be dedicated to this issue.

Reviewer 5:
The plan shown does not seem to address the fundamental limitations. It is difficult to see a path to success.

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

Reviewer 1:
The project is strongly aligned with the USABC 2023 goals for low-cost FC batteries, which is consistent with DOE priorities for vehicle electrification. So, it is clear that project supports DOE objectives.

Reviewer 2:
The proposed research clearly meets the DOE objectives.

Reviewer 3:
The research and development of fast-charging, low-cost Li-ion batteries will accelerate commercial viability of electric vehicles.

Reviewer 4:
The project team is developing the ability to produce quality cells and want to make high-energy cells at a low price. This is fully in line with DOE's mission.

Reviewer 5:
The overall goals of DOE of cost down with improved performance are unlikely to be met with large Si content.

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

Reviewer 1:
The project has made significant progress so far and does not appear to have realized any costly risks so far, so the remaining resources would seem to be adequate for the remaining work. CB 3 cells should be able to be built and tested by the end of the project.

Reviewer 2:
Resources and collaborative effort with DOE National Laboratories are sufficient to carry out the research.

Reviewer 3:
The project team is making steady progress to the targeted objectives.

Reviewer 4:
The reviewer noted that resources are sufficient.

Reviewer 5:
This is a 50/50 cost share with DOE. The team could spend more if it wanted.

Presentation Number: bat251
Presentation Title: Cathode Materials for Next Generation Lithium-Ion Batteries: Design, Synthesis, and Characterization of Low-Cobalt Cathodes
Principal Investigator: Jason Croy (Argonne National Laboratory)

Presenter

Jason Croy, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

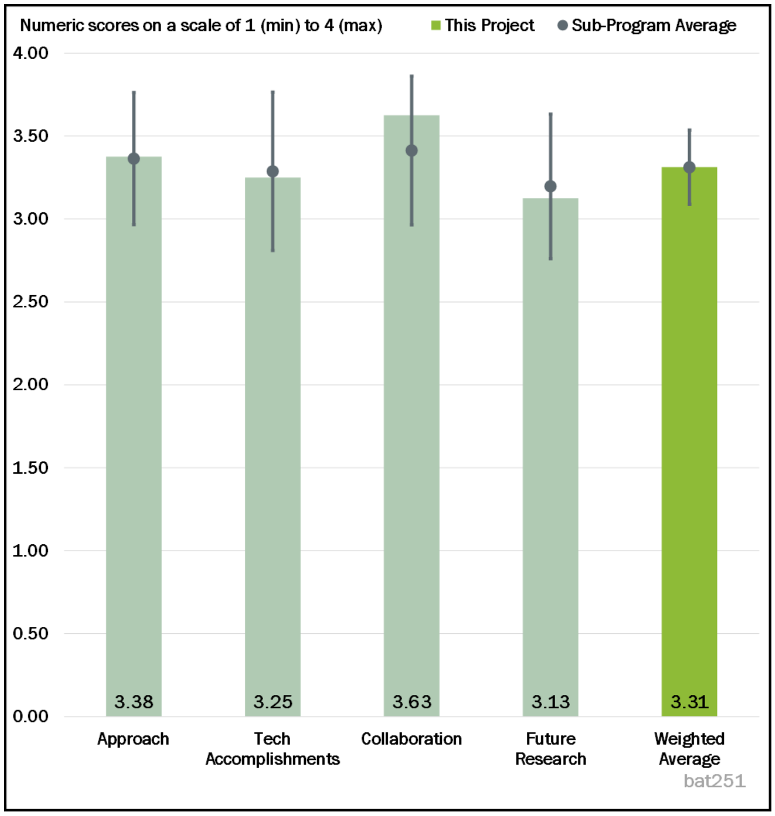

Figure 2-4 - Presentation Number: bat251 Presentation Title: Cathode Materials for Next Generation Lithium-Ion Batteries: Design, Synthesis, and Characterization of Low-Cobalt Cathodes Principal Investigator: Jason Croy (Argonne National Laboratory)

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:

In this project, the team proposed two approaches for lithium nickel dioxide (LNO)-based and Mn-rich-based oxides to reduce the Co content in layered cathodes. These two approaches are feasible to realize the purpose to eventually eliminate the use of Co in layered cathodes.

Reviewer 2:

Work was focused on studying the nickel oxide cathode and other low-Co materials. Systematic study of the effect of Mn doping in nickel (Ni) and Al coating on Ni shed a good light on the properties.

Reviewer 3:

Focusing on LNO and Mn-rich oxides is relevant and adequate. The work is well designed to generate reliable data and improve understanding of low-Co options

Reviewer 4:

The reviewer found the electrochemical results obtained with the LNO system to be impressive. The project team introduced aluminum (Al) as a dopant by ALD and wet-chemistry coating before high-temperature calcination. It could be of interest to see if the Al can be incorporated into the precursor structure during calcination, too.

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:
As mentioned earlier, the reviewer observed that the LNO electrochemical results were great. The LNO-based oxides with truncated polyhedron and octahedron morphologies are very interesting; they can help to better understand the electrolyte reactivity on the particle surfaces. Doping with Al using ALD resulted in uniform distribution of the additive improving the cycling performance. The study with single-crystals powders in collaboration with the Theory Group may yield important practical and theoretical insight.

Reviewer 2:
In the last year, the team has made significant progress in both directions of the studies. Specifically, the temperature-evolution behavior of pure LNO is quite meaningful and the electrochemistry results are beautiful. Also, the smaller introduction of Co into lithium manganese nickel oxide (LMNO) (only 5%) could drastically improve the electrochemical performance, which is also a striking achievement.

The reviewer offered the following specific areas to consider:

- It would be beneficial to involve the morphology evolutional results of LNO synthesized at 650°C, 665°C, and 685°C. The morphological differences might also be a reason to cause the distinction of electrochemistry.
- The Al surface treatment for lithium nickel cobalt oxide (LNCO) is unclear. Using X-ray photoelectron spectroscopy (XPS) depth-profile or cross-sectional energy-dispersive X-ray spectroscopy (EDS) line profile or mapping could provide the insight into the different bulk Al incorporation between ALD and wet coating.
- There needs to be more information to explain the reason why the ALD coating can introduce better bulk Al incorporation than wet chemistry.
- In a recent paper published in the *Journal of the Electrochemical Society* (JES), the author claims the unnecessary usage of Co in layered cathodes, it would be worth understanding the perspective from the team to consider having some minor Co content in both LNO-based and Mn-rich-based compositions.

Reviewer 3:
The grain-boundary transformation study and ordering are revealing, which can help with the design of future materials, especially the addition of a small amount of Co and that on Li/Ni exchange. It would have been useful to see electrochemical performance for more cycles beyond 100.

Reviewer 4:
The reviewer remarked that the good progress to generate more reliable LNO data is very useful.

Data on the impact of doping on LNO performance are relevant, but the reviewer was not sure how much new information was generated versus prior work. The reviewer did not understand the implication of particle-structure relevance.

Data on Mn-rich cathodes seem to confirm the importance of Co. It was hard to understand if the results suggest that removing Co is hard or impossible or provide some glimmer of hope.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
There was excellent collaboration among the teams.

Reviewer 2:
In this project, all participants mainly from five National Laboratories have shown the good quality of the experimental results, which is an indication of close collaborative relationships.

Reviewer 3:
The reviewer found the collaboration within the groups to be interesting. In particular, it is becoming very important for the collaboration between the theoretical group with the synthetic group.

Reviewer 4:
The reviewer noted that there was very good 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 team has proposed reasonable plans for next-year studies. The suggestion would be trying to avoid the usage of Co completely by considering other alternative elements, such as Mg, Al, etc.

Reviewer 2:
Re-examination of $LiNiO_2$ seems very important, in particular after the very good capacity results obtained by the project team. The Al dopant seems to be giving important improvements. Maybe introducing Al during calcination can be explored, too.

Reviewer 3:
The project has a good path forward including theoretical modeling.

Reviewer 4:
The focus on surface modifications and characterization is adequate.

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

Reviewer 1:
This project supports the overall DOE objectives and its purpose to reduce or even eliminate the usage of Co in layered cathodes, which is a critical topic of novel cathode compounds.

Reviewer 2:
This project is very relevant for the overall DOE objective of not using Co in the cathode powders. The team has shown great results and understanding of powders with no Co and very little Co contribution.

Reviewer 3:
Low-Co cathode material is relevant to the sustainability of Li-ion battery technology.

Reviewer 4:
This project supports DOE goals.

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

Reviewer 1:
To date, this project has delivered sufficient and meaningful results to meet the requirements of milestones.

Reviewer 2:
The project team may need additional support in case a production process needs to be scaled up.

Reviewer 3:
The project team has adequate resources and expertise.

Reviewer 4:
Resources seemed sufficient to the reviewer.

Presentation Number: bat252
Presentation Title: Cathode Materials for Next Generation Lithium-Ion Batteries: Diagnostic Testing and Evaluation of Low-Cobalt Cathodes
Principal Investigator: Dan Abraham (Argonne National Laboratory)

Presenter

Dan Abraham, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

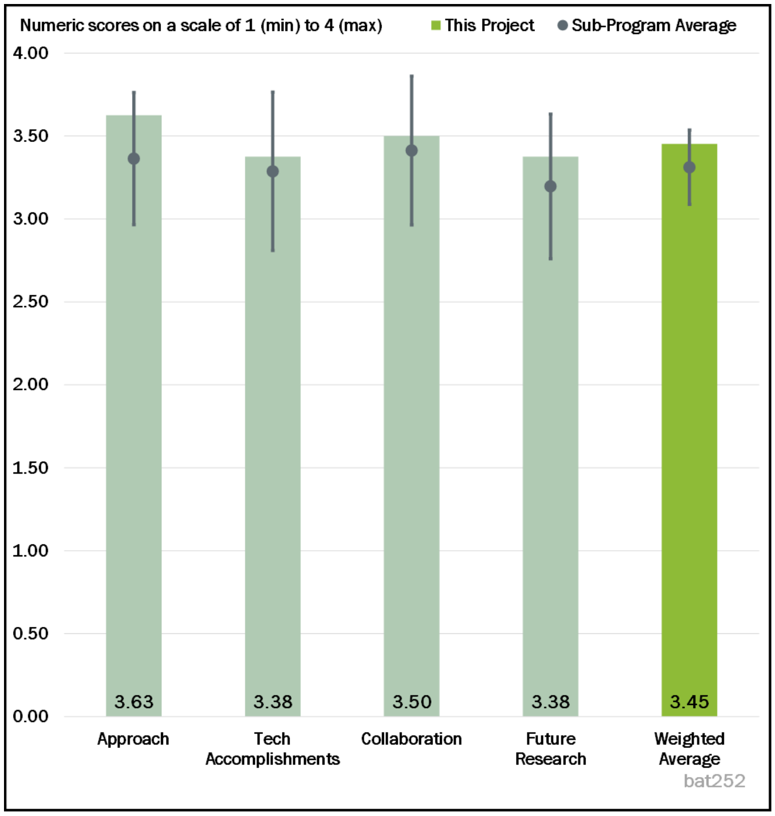

Figure 2-5 - Presentation Number: bat252 Presentation Title: Cathode Materials for Next Generation Lithium-Ion Batteries: Diagnostic Testing and Evaluation of Low-Cobalt Cathodes Principal Investigator: Dan Abraham (Argonne National Laboratory)

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 stated that this is an excellent multifaceted approach consisting of oxide development, cell testing, and post-mortem characterization.

Reviewer 2:

According to the reviewer, there is excellent work on the diagnostic testing and evaluation, which can be widely used by many other researchers. Most relevant aspects of the cathode material and testing are covered.

Reviewer 3:

The reviewer found the approach to be very good as the project team gradually replaced Co with Mn to study its effect on performance. The team has also fully replaced Co in one of these oxide cathodes. The capacity results were very impressive when testing Ni:Mn at 9:1. There was strong synthetic effort coordinated with testing and analytical post-characterization.

Reviewer 4:

In the last year, the team has determined the approaches of using electrochemical methods combined with some characterization techniques, such as differential electrochemical mass spectroscopy (DEMS), Fourier transform infrared (FTIR), nuclear magnetic resonance (NMR), differential scanning calorimetry (DSC), XS, Raman, etc., to understand the electrochemical mechanism of low-Co layered cathodes synthesized by colleagues. The techniques and protocol selections are reasonable and reliable.

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 there were very good capacity results with the pure Ni and Ni-Mn cathode material. Important results were obtained with in situ measurements, such as Raman, FTIR, and XPS. These methodologies could be extremely important to study and identify the degradation mechanism of these oxides, in particular the SEI. The results with solid-state NMR are giving important insight as they can detect bulk and surface Li.

Reviewer 2:
In the last year, the team has generated fruitful and comprehensive results for four types of Ni-rich and low- to no-Co cathodes. The long-term half-cell and full-cell results indicated the favorable performance of NMC-900505 and NM-9010 with the impedance, structural, and chemical studies. A deep understanding of these cathode compounds has been established.

Here are some specific comments from the reviewer:

- For the DEMS tests on these four cathodes, it would be worth knowing the reason to choose 4.2 V with prolonged holding to collect the O_2/carbon dioxide (CO_2) gassing data. In general, the preferred way to collect the gassing data would be during the galvanostatic charging at higher voltage, such as greater than 4.5 V.
- For DSC results, the current data can support the claim on "all four compounds have similar total heat release." However, the onset temperature of the first exothermic peak is also significant. Any observations or analysis on this should be discussed.

Reviewer 3:
Work is based on LNO structure in which a small amount of Co or Mn is doped. It is interesting to see that hold at 2.5 V capacity, which helps recover capacity. Also, the performance of the 0.05 Co and 0.05 Mn containing cathode is the best performing. In addition, the role of additives is examined.

In the gassing behavior, it is not clear to the reviewer why other organic gases (other than O_2 and CO_2) are absent. Is it an experimental error? Gases containing hydrogen (H) and F atoms were expected.

Reviewer 4:
According to the reviewer, there are useful insights that cell impedance after cycling is mostly due to the cathode. This is consistent with other prior work but provides more details and useful additional insights.

The best performing material seems to be the one with Co. Is this suggesting that some Co is necessary?

The gassing problem was highlighted but potential solutions were not discussed.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Collaboration was excellent.

Reviewer 2:
Collaboration seems to be strong between the different groups at ANL, NREL, Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), and Pacific Northwest National Laboratory (PNNL). Furthermore, the student support at University of Illinois, University of Rochester, and Oregon State University is very important for future developments in this field.

Reviewer 3:
In the last year, the team showed a good demonstration of the collaborative studies by testing synthesized materials from the collaborators and coordinated with other advanced characterization from collaborators.

Reviewer 4:
According to the reviewer, there was good 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 team has included nearly all necessary next steps for the upcoming fiscal year (FY) studies, such as the further diagnostics and characterization of scaled-up and surface-coated samples. One suggestion is to utilize the advanced synchrotron-based spectroscopic techniques in this team to conduct some in-situ cell characterization, such as hard- or soft- X-ray absorption spectroscopy as well as the surface X-ray diffraction or neutron diffractions to understand more about the chemical and structural evolution upon cycling.

Reviewer 2:
The study of performance degradation with ex-situ and in-situ spectroscopies should be encouraged. The scale-up of the synthetic efforts should continue. It is not clear to the reviewer, based on the presentation, why the project team is producing very small batches of this material (less than 100 g).

Reviewer 3:
The reviewer noted that this is an extension of the present work with additional in-situ spectroscopic techniques.

Reviewer 4:
Scale-up of additional oxides and the focus on surface optimization are relevant. Establishing electrochemical models to explain performance of low-Co oxide system would be very valuable.

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 of eliminating the usage of Co in layered cathodes, which is quite important for the development of high-energy cathode materials.

Reviewer 2:
Yes, this project supports the overall objective of decreasing the amount of Co used in these layered oxides. The project team already presented very good results with material that contains no Co, such as LiNi0.9Mn01. It would be interesting to know if the Mn-containing oxides are difficult to calcinate as it requires full oxidation of Mn during this process.

Reviewer 3:
Low-Co cathode material will help move the technology forward.

Reviewer 4:
The 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 range of techniques available for the project is impressive.

Reviewer 2:
This project has delivered satisfactory experimental results to meet the requirements of milestones, according to the reviewer.

Reviewer 3:
There are sufficient resources.

Reviewer 4:
This project may require additional support in case a scale-up of the precipitation process becomes necessary.

Presentation Number: bat253
Presentation Title: Cathode Materials for Next Generation Lithium-Ion Batteries: Theory and Modeling of Low-Cobalt Cathodes
Principal Investigator: Hakim Iddir (Argonne National Laboratory)

Presenter

Hakim Iddir, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

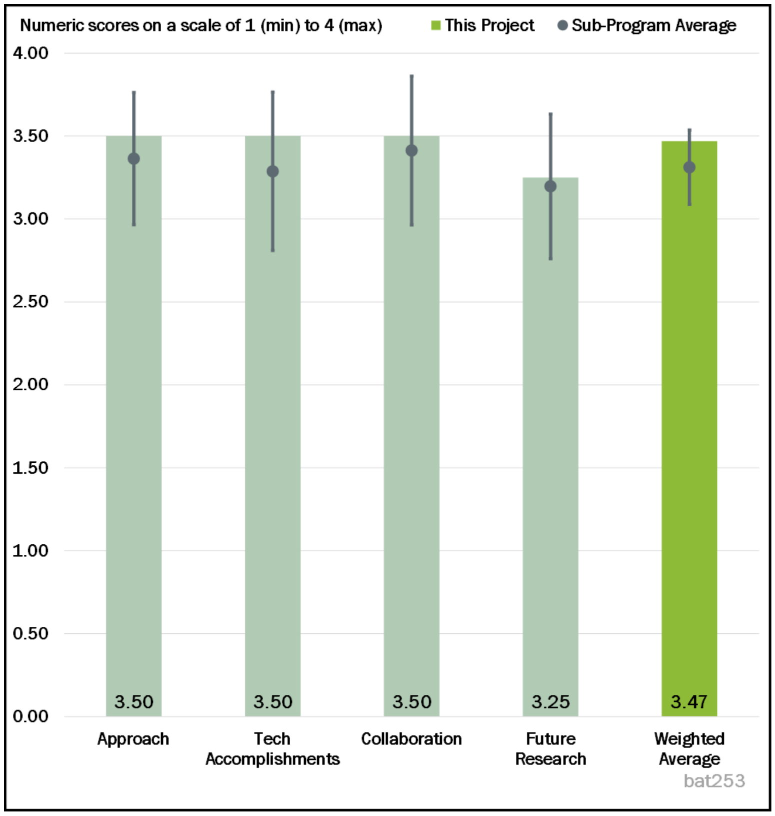

Figure 2-6 - Presentation Number: bat253 Presentation Title: Cathode Materials for Next Generation Lithium-Ion Batteries: Theory and Modeling of Low-Cobalt Cathodes Principal Investigator: Hakim Iddir (Argonne National Laboratory)

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 found this to be a very interesting approach where theoretical calculations are confronted with experimental results and, in some cases, help guide the experimental work. The project is well designed and feasible.

Reviewer 2:

This modeling work is appropriate to link very many experimental projects that are ongoing on low-Co cathode material design. The project could help link various studies together in providing a unified understanding that will help move the field forward.

Reviewer 3:

The team mainly leveraged the first-principle simulation tools to identify the role of Co introduction to the Li-Ni cation mixing, local structures, and Ni-Mn migrations. With some experimental results of single-crystal Ni-rich cathode materials, the feasibility of this approach has been confirmed.

Reviewer 4:

Use of modeling to understand the role of Co is a promising approach, 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 team accomplished the simulation tasks to justify the minimum amount of Co needed to stabilize the layered structure while suppressing Li-Ni cation mixing and Ni-Mn migrations. The results validated the existence of Co as inducing the ordered domain formation to increase the formation energy of cation mixing, which is beneficial for the perfect layered structure stabilization.

Reviewer 2:
The production of facet-dependent segregation in layered oxides was very interesting to the reviewer. It could be of great interest to really understand why the calculations predict a minimum of 1-3% Li-Ni exchange for all $LiNi_{0.5}Mn_{0.5}O_2$ configurations. Another interesting result is about the "zigzag" configuration on the Mn5050 oxide. Is it more stable because there is additional Mn-Ni atomic overlap in that geometry?

Reviewer 3:
Various insights are interesting, including energy correlation with Ni-Mn bonds, the difference between structures containing flower and zigzag patterns for Li-Ni exchange, dopant effect, and the dependence on the crystal facets. The principal investigator (PI) should show the comparison with the experimental electrochemical data to develop a confidence in the modeling results even though the NMR and lattice data are presented and compared.

Reviewer 4:
The team has generated useful insights into role of Mn-Ni interaction and effect of Li-Ni exchange. The impact of calcination and cooling conditions is also elucidated. Screening of dopants was comprehensive, but the reviewer struggled to understand the conclusions.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
It seemed to the reviewer that there is very good interaction within the groups, in particular between the theoretical researchers and the experimentalists. The reviewer was eager to see if the team can come up with a simple model that can explain the theoretical calculations and stability studies (energy numbers). It is nice to see that this study also helps the new generation of researcher at the University of Illinois, University of Rochester, and Oregon State University.

Reviewer 2:
The team used NMR, scanning transmission electron microscopy (STEM), and molten-salt synthesis to build the experimental complementary information about the local Li environments and the surface configuration of single-crystal particles. These collaborative results have proven the significance of the combination between simulations and experimental works.

Reviewer 3:
It is a good team and there is excellent collaboration.

Reviewer 4:
There is good teamwork.

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 is effectively planned and structured.

Reviewer 2:
The refining NMR fitting seems very important, and it seemed to the reviewer that it gave useful hints about the local Li-environments. It could be of interest to know how truncated polyhedron and octahedron morphologies have been prepared without revealing confidential information. That could be important at some point to judge if the process is scalable.

Reviewer 3:
The project proposed a clear next-step plan for this project. However, it could be more comprehensive if the collaborative studies between simulations and experimental works in this project can be further fused to generate more reliable results.

Reviewer 4:
Effect of element segregation would be useful. The reviewer was not sure if the kinetic modeling can be done that will be of useful (long enough) time scale.

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

Reviewer 1:
The reviewer stated that this project supports the overall DOE objectives of the synthesis and understanding of high-energy and long-lifespan Ni-rich cathodes, which are quite important for the development of next-generation cathode materials.

Reviewer 2:
The project supports the overall objective by replacing Co with Mn. Furthermore, the theoretical work adds a lot of validity to the experimental results.

Reviewer 3:
The work will help with fundamental understanding of cathode materials.

Reviewer 4:
The project supports 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 said that this project has delivered sufficient experimental results to meet the requirements of milestones.

Reviewer 2:
The PI has adequate computing facilities.

Reviewer 3:
There are sufficient resources.

Reviewer 4:

The resources may not be sufficient if, at some point, a production process for these cathode powders has to be scaled up.

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 five reviewers evaluated this project.

Project Relevance and Resources

80% of reviewers indicated that the project was relevant to current DOE objectives, 20% of reviewers indicated that the project was not relevant, and 0% of reviewers did not indicate an answer. 100% of reviewers indicated that the resources were sufficient, 0% of reviewers indicated that the resources were insufficient, 0% of reviewers indicated that the resources were excessive, and 0% of reviewers did not indicate an answer.

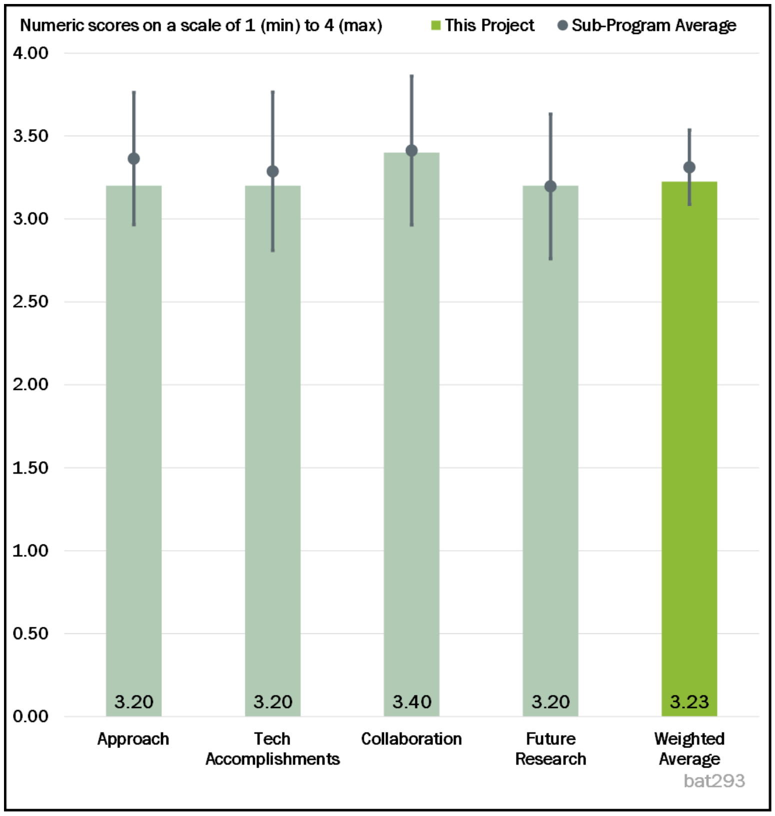

Figure 2-7 - Presentation Number: bat293 Presentation Title: A Closed-Loop Process for End-of-Life Electric Vehicle Lithium-Ion Batteries Principal Investigator: Yan Wang (Worcester Polytechnic Institute)

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:

Technical barriers impacting the project are identified upfront in the NMC research.

Reviewer 2:

The reviewer believed the idea is to collect Li-ion cells and, independent of the chemistry, collect the internal material and convert it to NMC622. This is a reasonable team where A123 will make ad test cells, Battery Resourcers will collect the Ni-based cathode, and then Worcester Polytechnic Institute will determine how to make fresh NCM622 from the material. The goal of the project is to make an NMC622 that is cheaper than starting from scratch. The team needs to perform the cost analysis.

Reviewer 3:

This appears to do recycling via complete decomposition of the materials back into virgin salts, which are then fed into the precursor precipitation process. It was unclear to the reviewer what the value to the larger community is for this approach. Regardless, the approach could certainly be more clearly communicated in the slides.

Reviewer 4:

The project was fairly well planned out, including a reasonable test plan, such that the technical barriers are mostly being well addressed. The cost barrier is adequately being addressed—there is at least some cost model data that indicate that the central recovery process could produce material that is 25% cheaper than virgin. Cost would have been better addressed if some work had been done to show the cost saving estimated for different levels of Co in the NMC; presumably, the cost advantage is less for lower Co content. According to the reviewer, there was no discussion about what percentage Co concentration in the recovered material would be for the quoted 25% savings to be expected. Similarly, like last year's comments, it is not all that clear how the sustainability target is being addressed. It would have been helpful to determine the percentage recovery of the waste material and how much is converted to usable cathode material. While this affects the cost savings, it probably affects the sustainability challenge more. It will not be very sustainable if only a small percentage of the end-of-life (EOL) material can be recovered. However, the performance and supply barriers are well addressed, and the project was well designed, overall.

Reviewer 5:
Recycling end-of-life LIBs to produce high-Ni NMC cathodes is a right strategy to reduce the cost and environmental impact. Not much detail about the technical approach is revealed in the report, but based on the testing results, the reviewer said that the project is well designed and feasible.

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:
Measured progress has been made in the research against the performance indicators.

Reviewer 2:
The reviewer noted that 24, 1-Ah NMC622 cells made with recycled cathode materials were delivered for testing. The results are comparable with the cells made with fresh materials. The team also tested one 11-Ah cell and got promising data.

Reviewer 3:
The project team needs to be able to collect the Ni-based cathode material and develop a scalable coating method on the way to producing NCM 622. The team has a reliable process for making coated NCM 622. It appeared to the reviewer that the team can make a material that is about 2% short of a control chemistry. The rate capability in 1-Ah cells is comparable. The team also demonstrated that it can generate large batches of materials that are comparable to a control, and the reviewer believes it is possible to make materials 25% cheaper than materials made from scratch.

Reviewer 4:
The project is nearing completion and appears to be generally on track to meet all deliverables although the testing of the 1-Ah cells and the fabrication and testing of the 11-Ah cells appear to be slightly behind and may need a short extension of the project. However, the project succeeded in producing the required 15 kg of recovered material to fully support the test plan, and the coin cell data indicate that the material quality is likely high enough to give good results. There is a reasonable probability that the 11-Ah cell testing will demonstrate that the recovered material is roughly equivalent to the virgin material control cells. So, the project will have a reasonable level of impact as expected.

However, even though the team notes that it has used diverse sources of spent battery material as inputs to the recovery processing, it was still not clear to the reviewer what levels of impurities can be handled, what diversity in the feedstock can be accommodated and still achieve process efficiency high enough to make the cost saving possible, or whatever other limitations on the processing window or feedstock are required to make the process feasible. Until these processing windows and feedstock requirements are determined, the impact of this project will be limited mostly to a demonstration that, at least under a certain set of conditions, shows the recovery process is possible and produces good material.

Reviewer 5:
It appeared to the reviewer that the team is using a relatively well known and understood cathode manufacturing processes. The technical accomplishment is not clear. Where is the value in this work?

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Collaborating with private industry and other DOE National Laboratories helps to scale up the commercialization process for this research effort. Fiat Chrysler Automobiles, General Motors (GM), and Ford involvement helps to identify the broader industry needs and their thought process.

Reviewer 2:
The project team has formed effective collaborations with A123 and ANL (for testing) and Battery Resourcers (for materials).

Reviewer 3:
The project appears to have assembled a good team with all of the expertise needed; there has been close cooperation among team members, which has helped keep the project roughly on schedule and looking to complete its test plan soon. One might expect the vehicle manufacturers to provide more than just spent batteries of various types—did they provide guidance on the testing plan, the analysis of the results, etc.? A close collaboration with the manufacturers could have included that kind of feedback loop. However, at least all of the necessary coordination of activities appears to have happened fairly smoothly with each partner participating at the required level to get to the end of the project.

Reviewer 4:
The reviewer noted that the team has established collaborations with reputable companies all along the recycling chain.

Reviewer 5:
According to the reviewer, collaboration and coordination across the project team is fine.

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 research proposal fits very well with gaps identified and provides a continuous improvement.

Reviewer 2:
Future plans are clear. The team is going to measure the cyclability of its materials compared to a control in 1-Ah and 11-Ah cells, refine their cost model, and look into producing higher Ni-content materials.

Reviewer 3:
There is not much left in the project, and the plan to complete the 1A-h testing and the 11-Ah build/test is entirely appropriate at this point. An update on the rough cost-savings estimate specifically for NMC622 or NMC811 would be nice if possible.

Reviewer 4:
It is important to build a cost model to show the economic benefits. Moving to NMC811 is also right direction. The reviewer also suggested performing an assessment on the nature of resource savings, like how much Co and Li are reused in the batteries.

Reviewer 5:
This project is ending.

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

Reviewer 1:
Yes, the project is/was well aligned with DOE priorities to establish a recycling capability for LIBs. Demonstration that the cathode material can be recovered and chemically reprocessed using co-precipitation chemistry to usable material at a cost savings is an important milestone for DOE and the EV community, and it will provide a benchmark for other recycling efforts that are more "direct" and try to recover, re-lithiate, and reuse the cathode mass more directly.

Reviewer 2:
Reducing the cost and environmental impact of battery production is in line with DOE objectives.

Reviewer 3:
Developing a way to collect and reuse materials from aged cells is critical to a sustainable ecosystem, which is at the core of DOE's activities.

Reviewer 4:
The reviewer stated the project meets the overall DOE objectives.

Reviewer 5:
The relevance and usefulness of this project was not clear to the reviewer. Perhaps it was poor communication in the slides and the recorded presentations. Regretfully, the reviewer was unable to submit questions before the cutoff.

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

Reviewer 1:
Partnering with private industry and DOE National Laboratories provides a sufficient resource to carry out the research.

Reviewer 2:
With just some cell fabrication and testing remaining, the project appears to have enough resources to complete the project.

Reviewer 3:
The project is 90% completed by the time of the report.

Reviewer 4:
The resources appeared sufficient to the reviewer.

Reviewer 5:
The resources are sufficient.

Presentation Number: bat332 Presentation Title: High Electrode-Loading Electric Vehicle Cell Principal Investigator: Mohamed Taggougui (24M Technologies)

Presenter

Mohamed Taggougui, 24M Technologies

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

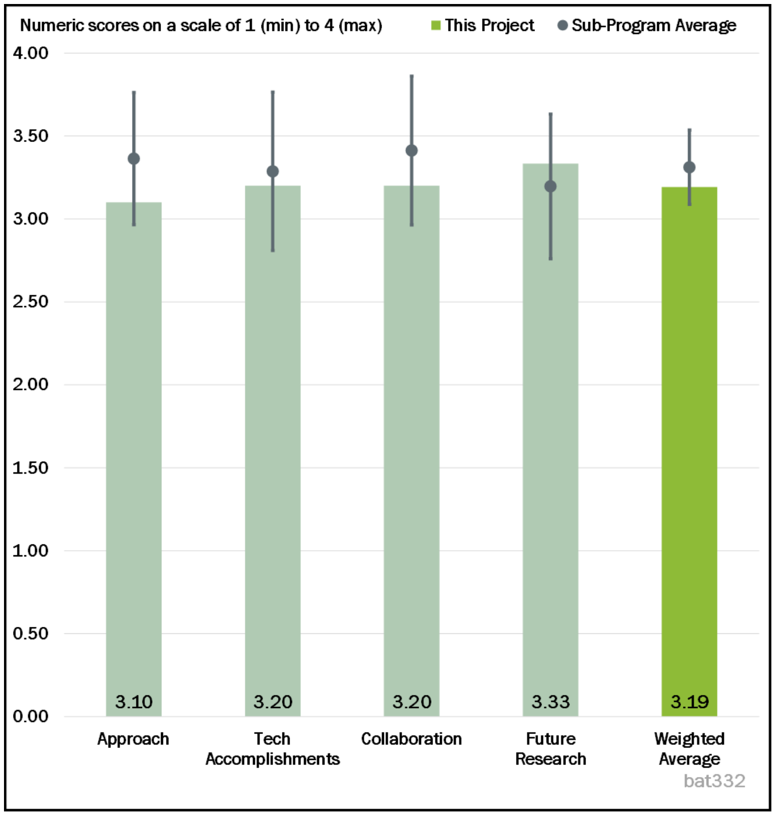

Figure 2-8 - Presentation Number: bat332 Presentation Title: High Electrode-Loading Electric Vehicle Cell Principal Investigator: Mohamed Taggougui (24M Technologies)

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 project clearly addressed the technical barriers associated with the high-energy battery systems in abuse tolerance and reliability aspects of Li-ion batteries.

Reviewer 2:

The project is based on 24M's semi-solid electrode technology, which enables high-electrode-loading cells for electric vehicles. The thick electrode format reduces or eliminates binders and separators and thus enables 25% cost reduction.

Reviewer 3:

Increasing the electrode loading is a direct way to lower the cost of cell. 24M presents a novel approach to manufacturing these thick electrodes. This project represents an interesting alternative to the standard approach to LIBs. With that said, the ultra-high loading electrodes have trade-offs that are unlikely to be overcome, such as electrolyte-transport limitations and an overall high cell direct current internal resistance (DCIR) due to lack of coated area (DCIR scales with coated area to the first order).

Reviewer 4:

The project was clearly well planned and executed. For the most part, the team appears to have focused on the correct barriers and provided reasonable solutions to most of them. From the milestone chart on Slide 7, electrolyte optimization and down-selection were part of each phase, but it was not clear to the reviewer how aggressive the program plan was in identifying and developing higher conductivity liquids that would have been more likely to reach higher energy capacities and/or higher C rates. It is possible that conservative choices in the electrolytes considered were made to ensure that viable cells could be produced and cycled to 1,000 cycles with 80% capacity retention—which would mean that the energy-capacity barrier and fast-charge barriers might not be well addressed by the project. Nevertheless, the project structure appears to have been sound, and generally most barriers were addressable within the design of the project.

Reviewer 5:
In general, the project approach is to use a semi-solid formulation to make thick electrodes, which should minimize the need for a large fraction of inactive components, thus saving dollars per kWh. Most of this year was spent on large cell construction and cycle testing. The reviewer's guess is that in its proposal the company said it would reach 350 Wh/kg but in the end achieved 276 Wh/kg. It would be interesting to know what did not work out in their approach to achieving this value.

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 project remained on schedule, met its milestones, achieved most of its performance goals, and, most importantly, demonstrated that a reasonably high-performing EV cell could be made with semi-solid electrode processing. As the team noted in the presentation, there is still some work to improve the EV cells to increase energy capacity, fast-charge capability, and low-temperature capacity retention, but overall the progress made by the project was noteworthy and should have an impact on EV battery technology.

Reviewer 2:
The deliverable cells (2.9 Ah and 52 Ah) achieve high energy density and specific energy, more than 1,000 cycles before EOL, and great tolerance property in electrical and mechanical abuse tests.

Reviewer 3:
The team made several large cells and met its deliverables in terms of number of cells and cycle life by achieving 276 Wh/kg, but there is are no calendar-life data shown. The reviewer mentioned excellent abuse tolerance. It would be nice to know why this cell design is capable of improved abuse tolerance over typical Li-ion cells.

Reviewer 4:
Technical accomplishments show more pictorial representation of the deliverables. It would have been beneficial to have a little more description associated with the pictures.

Reviewer 5:
The performance of the cells speaks to a respectable level of maturity. It was not clear to the reviewer that the main barriers will ever be overcome to enable commercialization in the automobile sector. More work showing the limitations related to charging would have been appreciated. The final-cell energy density was also not that impressive considering the ultra-high loadings. The reviewer assumed this is due to the high electrode porosity associated with the semi-solid electrodes.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Although there were only a limited number of partners in this project, any project of this size, duration, and complexity requires close coordination and collaboration across the partner set. This project excelled in this factor—optimization and down-selections occurred on time, cells got built and delivered, and independent testing got done. The reviewer remarked that a highlight of the project was its collaboration and coordination.

Reviewer 2:
The reviewer noted that the project team has collaborated with two National Laboratories on performance tests.

Reviewer 3:
The project team is fairly self-sufficient at this point. It is relying on ANL and SNL for cycle life and abuse testing, respectively.

Reviewer 4:
Collaboration and coordination seemed okay to the reviewer.

Reviewer 5:
Collaborating with ANL and SNL is good to utilize their testing resources. Industry partners will add more value in addition to the DOE National Laboratories if the long-term goal is to commercialize.

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:
Researchers identified the value-creation opportunities in the ultra low-cost and fast-charge automotive-capable cell.

Reviewer 2:
The company has identified future technical opportunities on making ultra low-cost and fast-charging batteries. Their current deliverable cells are of C/3 charge rate. An improved charge rate will increase the commercial compatibility of their products, according to the reviewer.

Reviewer 3:
Future research includes improving the calendar life (the reviewer was not sure how) and improving the fast charge by using a bimodal distribution of the cathode material and increasing the conductivity of the electrolyte (again the reviewer was not sure how).

Reviewer 4:
Project is complete.

Reviewer 5:
This criterion is not applicable as the project has been completed.

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

Reviewer 1:
The project clearly supported DOE objectives by addressing an important question about whether a reasonably high-quality EV battery could be produced using a semi-solid electrode manufacturing process where the same liquid serves as the solvent, carrier, and cell electrolyte. The project reasonably demonstrated that a viable EV cell with moderately high energy density (276 kWh/kg), good abuse-testing characteristics, and low-performance variability could be produced using the semi-solid production approach and therefore at the significantly lower cost promised by this manufacturing approach (e.g., fewer steps, lower balance of materials required). Although the Phase 3 cell will not meet the USABC 2020 goal for cell-level, usable specific energy, the results of the project should nevertheless support DOE objectives by demonstrating the general viability of the novel production technique for high-quality EV batteries.

Reviewer 2:
This project enables industrial-scale production of low-cost and high-performance batteries for electric vehicles.

Reviewer 3:
The project seeks to meet DOE's goals for energy-density goals, cycle life, and improved abuse tolerance. The technology appears to meet the cycle-life and abuse-tolerance targets but falls short on energy density, fast charge, and calendar life. There is no explanation provided.

Reviewer 4:
The project has an Interesting approach to reduce cost. The reviewer remarked that it is good to have done the evaluation although it is unlikely to be implemented.

Reviewer 5:
The reviewer stated that the project meets 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 researcher is capable of carrying out the research with minimal collaboration and has sufficient resources.

Reviewer 2:
The company seems to be making good progress.

Reviewer 3:
This is a completed project with 50% funding share from the company.

Reviewer 4:
The reviewer stated that resources are sufficient.

Reviewer 5:
The project was completed in 2019.

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 five reviewers evaluated this project.

Project Relevance and Resources

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

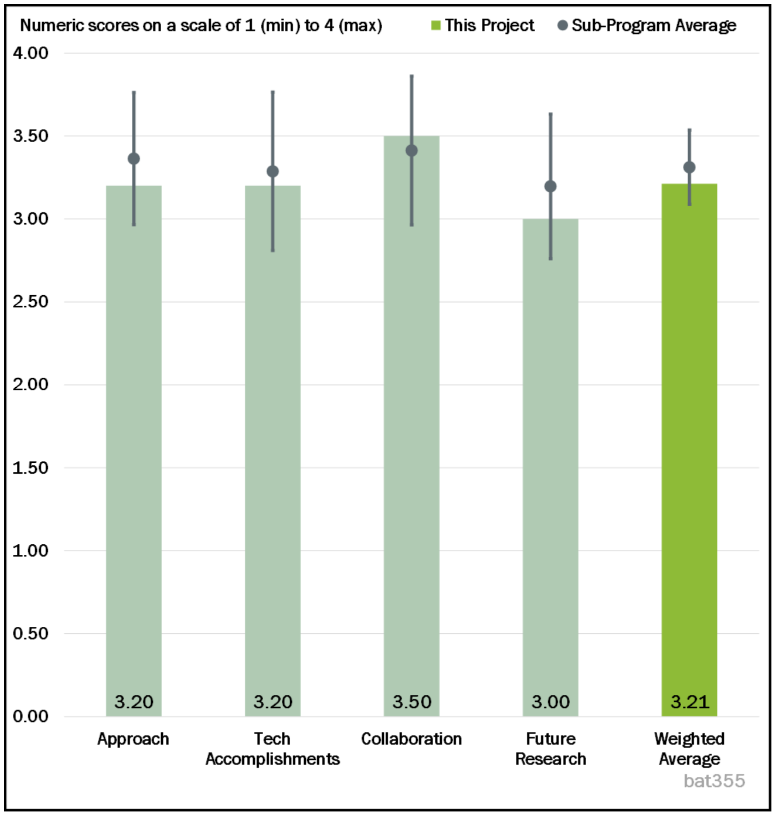

Figure 2-9 - Presentation Number: bat355 Presentation Title: Development of High-Performance Lithium-Ion Cell Technology for Electric Vehicle Applications Principal Investigator: Madhuri Thakur (Farasis Energy)

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 technology approach has been carried out by addressing key current barriers to achieving high capacity, long life cycle, and safety thoroughly.

Reviewer 2:

The main target of the project is to develop a high energy-density battery (330 Wh/Kg beginning of life and 280 Wh/Kg at 1,000 cycles) at low cost ($0.10/Wh). The approach is a combined effort among National Laboratories and industrial companies to improve electrode chemistry (Si-based anode and Ni-rich cathodes), electrolytes, and cell design. This approach seems to work well as it teams up expertise of different fields to systematically tackle the barriers in battery advancement.

Reviewer 3:

For this complicated problem, the team plans to look at cathode materials from seven different suppliers and electrolytes from three suppliers and investigate electrode formulations and cell designs. The reviewer indicated that the team does not explain how it plans to arrive at a final chemistry and a final cell design.

Reviewer 4:

The reviewer asked for the team to please put greater focus on volumetric energy density and swelling (during one cycle and after many cycles). A company such as Farasis should have the ability to target these more practical matters compared to a university or National Laboratory. The reviewer noticed the response to previous reviewers' comments, but the statement from the presenter should be supported by data. This should be considered a higher priority than it is.

Reviewer 5:
The project has been following a fairly comprehensive work plan with a large test matrix of anode material, cathode material, electrolytes, additives, and even binders in pursuit of the Gen 2 goal early in 2021. Although comprehensive, it looks very much like trial-and-error. If possible, it would have been better if there had been some indication of why certain combinations have been tried and why others have not. Is the approach simply to try each and every possible combination of the available material? It looks like the number of candidates here was at the limit of the project time available—any more and the project would have been further behind.

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:
Sufficient progress has been made in evaluating the active anode and cathode materials and compared very well against the performance indicators.

Reviewer 2:
The project team has designed and fabricated the Gen 2 cell of 330 Wh/Kg in 500-mAh capacity for the test as scheduled.

There is no cost assessment for making the cells in pilot-plant scale. Cost saving is one of the major objectives and the project is close to completion.

Reviewer 3:
The team does end up achieving 1,000 DST cycles and 310 Wh/kg; however, it did not appear to the reviewer as though the team will reach a year of calendar life at 100% SOC. The team moved to SiO but required a prelithiation step to improve the energy density. The cycle life has dropped to around 500 cycles. Moving to three other Si materials, the team gets back to 800 cycles at 330 mAh/g. It is not clear as to what led to the increase in energy and improved cycle life. The team does not mention the amount of carbon and binder it used for either electrode or the capacity per centimeter squared (cm^2) it achieved.

Reviewer 4:
The cycling depth of discharge appears to be very generous and perhaps not as aggressive as it should be for automotive applications. The reviewer asked the team to please consider cycling down to 2.8 V at least. There are no results shown for gassing at elevated temperatures, which could be a showstopper for automotive.

Reviewer 5:
The project certainly has made reasonably good progress toward its final goal and successfully delivered Gen 1 cells to the National Laboratory partner, which met performance targets (except for calendar life at high SOC). The prospect of delivering Gen 2 cells that also meet the performance targets when tested at the National Laboratories is pretty good based on the preliminary data provided for non-production-quality test cells that have been cycled to 800 cycles.

However, the cost target of $0.10/Wh does not appear to be addressed anywhere in the provided material. Where is the project in term of meeting its cost target in the Gen 2 cell to be delivered in early 2021? Also, the Gen 2 prototype data focused on capacity retention and did not include data on anode conductivity (discharge capacity rate [DCR]) and stability, so it was not entirely clear to the reviewer that this aspect has been fully investigated and brought under control for the Gen 2 demonstration. However, it does appear that most technical barriers are being overcome. Progress on the cost barrier was unclear to the reviewer.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
There are an outstanding number of partners on this project.

Reviewer 2:
The reviewer found excellent collaboration with many DOE National Laboratories and industry partners. Industry partners bring in the commercial point of view, and DOE National Laboratories add insight to the detailed aspects of development.

Reviewer 3:
There are many collaborators in this project: mostly material suppliers and National Laboratories for performance verification. It seemed to the reviewer like there has been very good coordination of the effort despite all of the required inputs. The delays in the project appear to have come from overcoming performance issues with the cells and not in getting materials, getting the cell fabricated, and getting the cells tested. All of that coordinated effort seems to be going well among the project partners.

Reviewer 4:
The team includes two National Laboratories and several industrial companies; all have different contributions.

Reviewer 5:
Cross interactions were not clear to the 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:
There is not much left to do on this project, and the plan to finish and close out the effort is straightforward and logical. According to the reviewer, there are no issues here.

Reviewer 2:
To complete the project, the team will build 40-Ah cells with projected energy density of 310 Wh/kg.

Reviewer 3:
The reviewer noted that the project is ending soon.

Reviewer 4:
The reviewer did not see any future research areas from the researcher except building a 40-50-Ah cell.

Reviewer 5:
Despite being nearly complete (75% of the way there), the project team does not provide a future research slide.

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

Reviewer 1:
The project is very well aligned with DOE objectives to reach 330-350 Wh/kg cells at a cost of $0.10/Wh. The project was specifically designed to meet these DOE goals within a 3-year project, again supporting DOE objectives for electric vehicles in 2022 and beyond.

Reviewer 2:
Batteries of high energy density, low cost, and longer cycle and calendar life will make the EV commercially viable.

Reviewer 3:
This project looks to improve cell capacity toward 350 Wh/kg with long cycle and calendar life. The project team is getting close to the first two.

Reviewer 4:
The reviewer said that Si is an important material to develop and potential aid DOE to achieve their goals.

Reviewer 5:
Research does meet 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 research team has sufficient resources and is also collaborating with many DOE National Laboratories and including an industry partner also.

Reviewer 2:
The project appears to have sufficient, but not excessive, resources to complete the project as planned under the no-cost extension (NCE) granted by DOE.

Reviewer 3:
All the tasks are on schedule so far, but given the COVID-19 situation it may be somewhat delayed.

Reviewer 4:
The team has an extensive program and is meeting the milestones.

Reviewer 5:
Resources are sufficient, according to the reviewer.

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

Presenter

Mike Slater, Farasis Energy

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers indicated that the project was relevant to current DOE objectives, 0% of reviewers indicated that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers indicated that the resources were sufficient, 20% of reviewers indicated that the resources were insufficient, 0% of reviewers indicated that the resources were excessive, and 0% of reviewers did not indicate an answer.

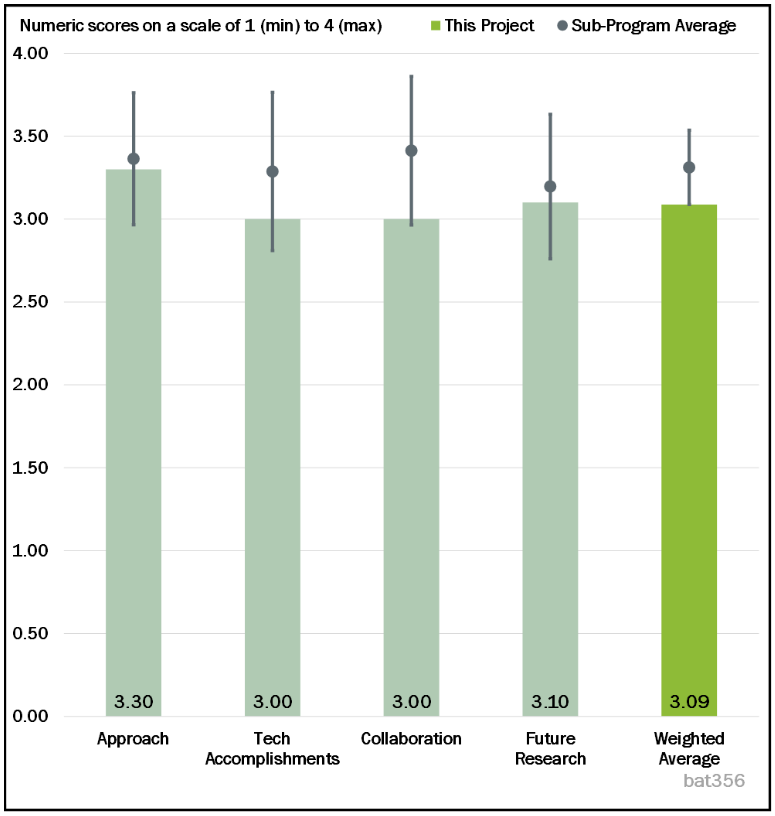

Figure 2-10 - Presentation Number: bat356 Presentation Title: Lithium-Ion Cell Manufacturing Using Directly Recycled Active Materials Principal Investigator: Mike Slater (Farasis Energy)

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:

Researcher clearly identified the barriers in recycling Li-ion batteries and developed a well thought out technical plan to address it. The project is well designed to address all the technical barriers.

Reviewer 2:

The project is to build LIBs with directly recycling of active-electrode materials. This is supposed to be a cost-effective approach and therefore important as one of the problems in battery-materials recycling is the high expense.

Reviewer 3:

Direct recycling of active materials is the least energy and cost intensive approach to the recycling of LIBs. A careful evaluation of the feasibility of this approach is warranted. The project appears to be systematic in its design and feasibility. The delays are understandable and not cause for concern.

Reviewer 4:

The approach is to acquire materials from different sources, to separate the carbon and NMC, make new cells with recycled materials, and compare to cells with virgin material. It was not clear to the reviewer what the team is going to do when the cells with recycled material do not perform as well as cells with pristine material.

Reviewer 5:

The project appears to have been set up more like a proof-of-principle demonstration rather than a project to address specific technical barriers to cathode material supply and sustainability. The question—can NMC material be directly recycled into a battery with performance close to one built with virgin material—is not really the question;- most will readily believe that it can be done as a proof-of-principle (or already has been done). The project would have been better designed if it had directly addressed the key barriers to direct recycling of cathode materials: scalability of the separation and re-lithiation processes with cost-effective processing and the ability of that set of processes to handle variability in feedstock to support more than one commercial-use case (e.g., recycling scrap manufacturing of controlled, known composition). The project claims that it was designed to look at the feedstock variability question, but the work plan does not support that kind of assessment.

Similarly, although the project has been able to produce enough kilograms of material to support the first test cells, it was not clear to the reviewer if any of the project was really designed to examine scalability of the processes that are being used. This is surprising because one would think that the innovation that Farasis brings to the table is their separation and re-lithiation processes and that there would have been production targets for kilograms of material far in excess of what was needed for cell testing to demonstrate that the scalability barrier could be overcome. Instead, the project is well behind its original schedule, and although the cause was not specifically identified, it is probably safe to assume that the laboratory processes are not scaling well at the kilogram scale and the material is not pure enough and/or contains too many trace contaminants. In any case, the current plan would only be the very beginning of a well-designed plan to explore the effect of feedstock variability, which is a very large barrier to cathode-material sustainability via direct 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:
The project team has identified the complexity in the cell chemistry from recycled materials and developed a feasible recovery scale-up process, characterized the active material properties of NMC111, and compared them to pristine powdered materials to identify any variations.

Reviewer 2:
So far, the team has completed CB 1, and the testing results show inferior performance compared to cells built with pristine materials. However, the difference in capacity and FCE is within 15%. CB 2 was scheduled but delayed.

Reviewer 3:
The team has been working under a no-cost extension since January of 2019. The reviewer remarked that there was no explanation of why this program is so far behind, despite COVID-19. The team has test results from a first build that shows less performance from recycled material. There was no indication of how the team would change their processes to improve the performance. The project team is awaiting testing of its second cell build. No data were provided on the contribution from LBNL.

Reviewer 4:
Progress is being made although behind schedule (even before COVID-19). The drop in the reversible capacity of the cathode active material seems to potentially be a showstopper. More explanation obtained through experimentally driven studies is needed, according to the reviewer. Is this seen as inevitable or just a sign of the immaturity of the process? What is the mechanism?

Reviewer 5:
The reviewer commented that the project is clearly very far behind its original schedule, while the progress over the last year appears to be steady but unremarkable. The project will soon finish the second cell build and will probably have enough material from the module breakdown and recovery to build the third set of cells. The prospect of finishing in 6 months is not impossible, but any more delays will put that target in jeopardy.

The first-cell data were a significant accomplishment, according to the reviewer. The results were not surprising as they were very consistent with the underlying assumption that bulk NMC structure remains largely the same, but surface chemistry and aggregation changes affect performance versus virgin material. The results would have been better if there had been some data on the condition of the particles, their surface chemistry and aggregation, and the level of impurities and defects before and after the re-lithiation/reconstruction processes to show the effectiveness of such processes in recovering the performance of the virgin material.

Similarly, some data on the efficiency of the separation processes (mechanical and/or liquid separation) would have helped make the case that the direct processes would help to achieve sustainability in the cathode-material supply chain. The reviewer noted that recovery of less than 50% of the possible material may not support sustainability of NMC powders.

Finally, the material gap chart indicated that perhaps only 28% of recycled content may be possible in cathodes with recycled content due to low energy-capacity numbers. While not a particularly encouraging number, it was an important parameter to establish. It helps the credibility of the life-cycle analysis and techno-economic model for direct recycling to have a reasonably good idea how much recycled content can really be incorporated.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
There is only one partner (LBNL) teaming with Farasis, and the level of collaboration and coordination appears to be very good (assuming that process scalability has been the issue in the delays and not getting the materials characterized at the National Laboratory). The contributions of the National Laboratory are obvious as the characterizations of the material are very necessary. In fact, one could argue that the project could benefit from more characterization data, particularly surface information, etc.

Reviewer 2:
The research collaboration with LBNL to leverage some of the testing resources from the Laboratory is a good strategy. Collaboration with a few more DOE National Laboratories and private industry would broaden and speed up the development process in addressing the difficulty in separating direct-recycled active materials.

Reviewer 3:
The project team has collaborated with LBNL for advanced chemical diagnostics and materials characterization. The reviewer remarked that this is important as it will help to understand the factors affecting the performance of the recycled batteries. However, there are no activities or results reported.

Reviewer 4:
Other than LBNL, the reviewer was not sure of any other partners. Farasis is a cell manufacturer so it already is a material supplier and source of aged batteries so the company must feel it does not need additional partners.

Reviewer 5:
The reviewer commented that it would have been helpful to see more precise examples of collaboration although there is only one external 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 project team has identified a clear path for future research in complete material recovery from module feedstock and relevant testing procedures.

Reviewer 2:
The reviewer said that the project is to be completed in the NCE period through June 2020, which clearly will be further delayed due to COVID-19.

Reviewer 3:
The team is going to collect material, build test cells #3, and measure their performance. The team does not explain how they intend to optimize the process of material recovery.

Reviewer 4:
The reviewer would have appreciated bringing in a greater mechanistic understanding regarding differences in the material performance. It seems that the UC-Berkeley collaborator would be able to help out with diagnostics. The project is near its end.

Reviewer 5:
The project is nearly complete (hopefully within 6 months) so there is not much latitude in the proposed future research. The second and third sets of test cells will be built and tested, and the results will be analyzed to demonstrate the potential value of the direct recycling processes. The final analysis should include (as promised) integrating the process model with electrochemical test data to quantify the impact of recycled materials on technology lifetime. The reviewed said that the raw battery-test data will not mean much by themselves.

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

Reviewer 1:
Yes, the work is consistent with DOE efforts to develop a sustainable supply of cathode materials and other battery components to enable vehicle electrification. Determining the commercial potential for direct recycling is important and enables a comparison with the chemical-recycling approaches involving re-precipitation of the metal oxides from solution. Re-precipitation may be more favorable for a while as the feedstock changes with battery design changes (NMC111 to NMC532 to NMC811), but once the battery cathode technology stabilizes at low- or no-Co content, the comparative advantage of direct recycling rises—and it would support DOE goals to have the necessary direct- recycling processes in place and ready to scale.

Reviewer 2:
The reviewer stated that the project meets the overall DOE objectives.

Reviewer 3:
Building LIBs from recycled active materials potentially will reduce the cost and impact to the environment.

Reviewer 4:
Finding a way to collect and recycle the materials in LIBs is critical to a sustainable economy and keeping the price down.

Reviewer 5:
Recycling is critically important to create a sustainable and commercially viable electric car eco-system.

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 appears to have sufficient resources remaining on the cost-share side of the balance sheet to complete the project in 6 months under a second NCE, assuming the pandemic disruption lessens.

Reviewer 2:
Sufficient resources are there for the researcher to address the barriers and technical accomplishments.

Reviewer 3:
The reviewer indicated that funding is at the appropriate scale for this project.

Reviewer 4:
The delay in achieving the stated milestones is not due to the funding insufficiency.

Reviewer 5:
This program is taking a much longer time than originally envisioned. One assumes that if more resources were dedicated to the project, work would be accelerated.

Presentation Number: bat357
Presentation Title: Thicker Cathode Coatings for Lithium-Ion Electric Vehicle Batteries
Principal Investigator: Stuart Hellring (PPG Industries)

Presenter

Stuart Hellring, PPG Industries

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

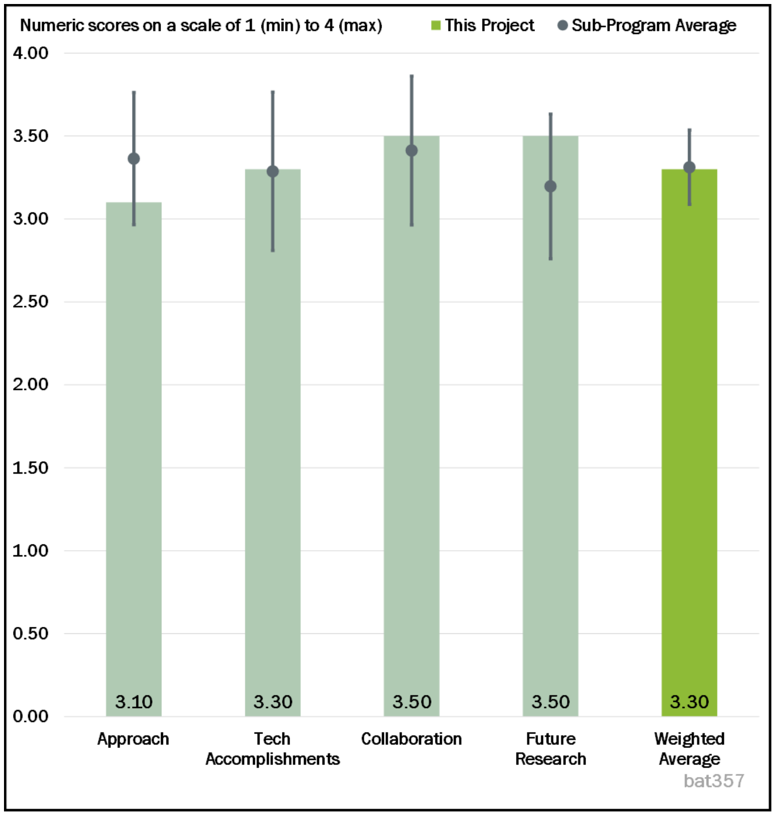

Figure 2-11 - Presentation Number: bat357 Presentation Title: Thicker Cathode Coatings for Lithium-Ion Electric Vehicle Batteries Principal Investigator: Stuart Hellring (PPG Industries)

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 team has developed well thought out, relevant metrics and targets for anodes and cathodes to reduce the battery size, weight, and cost by using thicker coating technology. The reviewer praised the project as being very well designed with a feasible approach to address the barriers.

Reviewer 2:

The team's approach is using PPG binder for NMC622 with higher areal energy density and eliminating the toxic NMP in the cathode slurry. The reviewer noted that the approach works well as indicated by the performance tests.

Reviewer 3:

The overall approach is to develop a means of producing thick electrodes without the use of NMP. In general, the team will start by making electrodes of 20 mg/cm^2 and gradually advance to 40 mg/cm^2 cathode material. The reviewer remarked that the team does not explain the levers it has in improving its process. The presentation comes off as if the team has a formulation and it just has to go make the electrodes. The team mostly shows cycle performance in the accomplishments but little on how it made such progress.

Reviewer 4:

The project appears to have focused on the manufacturing of thick electrodes. While the approach taken to achieve this goal appear reasonable, there are additional barriers that may need to be addressed to enable the introduction of high loadings into automotive cells. Furthermore, there appears to be little discussion of the density of the electrodes. The reviewer's view was that just having high loadings alone is not sufficient to have a more attractive product.

Reviewer 5:
While the project (nearing its completion) appears to have produced some valuable results on non-NMP cathode binders and the production of thick electrodes (particularly cathodes), the reviewer was of the opinion that the project was only moderately well set up to address the barriers of thick electrodes and NMP use in battery manufacturing,. The need for thick anode development and pilot-plant production should probably have been anticipated, and a battery manufacturer or similar cell developer probably should have been recruited from the start. It appears that the Pennsylvania State University (Penn State) was recruited to help in the development and that the research focus in the final year had to be redirected toward this effort. While approved by the USABC sponsor, this could have been avoided in all likelihood.

Also, the two technical barriers being addressed are not necessarily coupled as the project plan implies. Once the team identified a suitable, safer, greener solvent to replace NMP solvent in cathode production of normal thickness electrodes (i.e., barrier #1), the reviewer indicated that the comparisons of the PPG binder to the NMP binder should have stopped there. While it is fine to promote the PPG binder for thicker electrodes, the comparison of performance of the thicker electrodes with PPG binder needs to be made with other advanced thick electrode fabrication methods, like semi-solid processing, rather than with the NMP process for thin electrodes. The barrier for thick electrodes exists primarily because cathode-preparation methods for thinner electrodes using NMP do not scale well to producing thicker electrodes. Also, the comparison for thick electrodes (1st batch) versus NMP binder were done at the University of Michigan Energy Institute (UMEI) facility, which may not have the best, most advanced technique for thick electrodes using NMP. Again, the barrier would have been better addressed with the involvement of a battery manufacturer and with comparisons of the PPG binder with other advanced, thick-electrode fabrication approaches or any commercial cell with the equivalent areal density regardless of how the cathode was prepared.

Finally, the other issue with thick electrodes (i.e., barrier #2) is that they have power limitations when cycled at a high rate, even when they can be formed into a pouch cell successfully. The project would have been better designed to address the thick-electrode barrier if some data at high charge/discharge rates had been planned. Cycling at C/3 is okay, but it does not tell the whole story on the ability to access all of the active material in a thick electrode.

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:
Technical accomplishments are nicely formulated with a step-by-step approach. The project team characterized the baseline cathode performance with PPG binder to that of polyvinylidene difluoride (PVDF)-NMP binder and furthered with targeted cathode performances.

Reviewer 2:
The team has demonstrated that it can manufacture electrodes with high loadings and achieve reasonable cycle life at the C/3 rate. There appears to be knowledge gained in both new materials (binder-solvent systems) as well as manufacturing process.

Reviewer 3:
With PPG binder, the team's 22 mg/cm^2 loading NMC622 reached 91.5% capacity retention with 1C charge rate at 1,000 cycles, while the control cell with PVDF was at 84.7%. The team also achieved 80% retention at 500 cycles with 30 mg/cm^2 loading and 85% at 450 cycles with 40 mg/cm^2 loading (with C/3 charging rate).

Reviewer 4:
The project team's formulation appears better than the typical NMP-PVDF binder system. As the team moves to higher loadings, the peel strength reduces as does the cycle life. The reviewer commented that there is no explanation or hypothesis provided to explain these results. Thus, it is not clear how the team hopes to improve on either, other than through "modifications." The team shows that it can successfully coat 40 mg/cm^2 electrodes and matching anodes. The capacity fade is too high to meet the USABC goal of only 20% loss in 1,000 cycles.

Reviewer 5:
Again, promising results were obtained by the project so there will be some impact on battery technology. The PPG binder system looks like a promising alternative to NMP for cathode production, but without any specifics about the solvent (how much greener is it, etc.?), it is hard to predict the impact on addressing the NMP barrier. Also, there was no cost analysis (% savings or cost) or lifecycle analysis to ensure that the solvent has a lower environmental impact than NMP and is affordable. There were also no data on the manufacturing variability of the new solvent or process, so it was not clear to the reviewer if the data presented for the "normal" baseline cells represent a real breakthrough or not. The initial results are certainly encouraging for its replacement of NMP, but there would have to be a lot more data on the process collected to conclude that the NMP barrier to battery manufacturing is about to go away.

Similarly, the data on the thick-electrode production are encouraging, but the focus on only C/3 cycle data limits the enthusiasm. The thicker electrodes have a long way to go—calendar life testing, power measurements, abuse testing, gassing, DST, etc. The C/3 cycling results on the final set of cells will of course be an important first step when they are obtained, but there will be a lot more to do, much of which will probably require state-of-the-art battery manufacturing in lieu of lab-scale/pilot-scale production. The performance issue with thick electrodes is not just due to the shortcomings of the binder in fabrication.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented that Involvement with academia, industry, and a DOE National Laboratory is a great way to address the technical barriers and speed up the development process

Reviewer 2:
PPG collaborated with a National Laboratory and universities, as well as other industrial companies in this project.

Reviewer 3:
It appeared to the reviewer that many hands from different organizations helped to make this work successful.

Reviewer 4:
The project team has a world-class material supplier, a group that appears good at making pouch cells, and a company willing to test the cells. It was not clear to the reviewer that the team or a partner is able to successfully identify the reason for the rapid capacity fade.

Reviewer 5:
It was not exactly clear to the reviewer how some of the contributors (UMEI, Penn State, and the Battery Innovation Center) were recruited and participated as part of the team, but PPG should be given some credit for stitching together a partner set that has gotten them to this point. In the end, they seem to have forged collaboration where they needed and gotten enough coordination to be ready for the final test cell build/test. However, a clearer, better plan for collaboration and coordination at the outset of the project might have shortened the timeline on this 3-year binder development process and allowed more extensive testing on the thickest electrode cells.

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 proposed future research is a continuation of the improvement process from the present research to address the technical barriers and gaps—a good strategy.

Reviewer 2:
The project is pretty much completed, according to the reviewer. The only task left is to deliver the final target cells (40 mg/cm^2 loading) for testing, which will depend on the COVID-19 situation.

Reviewer 3:
The project is nearing completion. There really is not much to do other than the planned final build/test with the thickest electrodes.

Reviewer 4:
Apparently, all that is left to do is to cycle the final cell deliverable.

Reviewer 5:
The reviewer said that the project is ending.

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

Reviewer 1:
Generally, the project is well aligned with DOE objectives for vehicle electrification by addressing two challenges: reducing the widespread use of NMP solvent in cathode production and developing high areal density cathodes for longer range batteries in vehicles. The reviewer noted that the project has set the stage for further research and development to address these important challenges.

Reviewer 2:
The project presented research that meets all the DOE objectives.

Reviewer 3:
PPG has made cathodes with no toxic NMP in the binder, while achieving better performance and increased areal energy density.

Reviewer 4:
Making higher energy density cells is a high priority for the DOE. In this way, costs per kWh can be reduced.

Reviewer 5:
The reviewer suggested that future work should focus on achieving high energy density and fast charge (25 minutes [min.]) with high loading electrodes.

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

Reviewer 1:
It appeared to the reviewer that the project is meeting its deliverables and making reasonable progress.

Reviewer 2:
Resource allocations have been identified very well.

Reviewer 3:
The project will be completed shortly after pandemic restrictions are lifted, and the reviewer indicated that there appear to be enough resources left to complete this final amount of work in the next couple of months.

Reviewer 4:
The project is little delayed due to COVID-19.

Reviewer 5:
Resources are sufficient.

Presentation Number: bat359
Presentation Title: Status and Challenges of Electrode Materials for High-Energy Cells
Principal Investigator: Stanley Whittingham (Binghamton University)

Presenter

Stanley Whittingham, Binghamton University

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

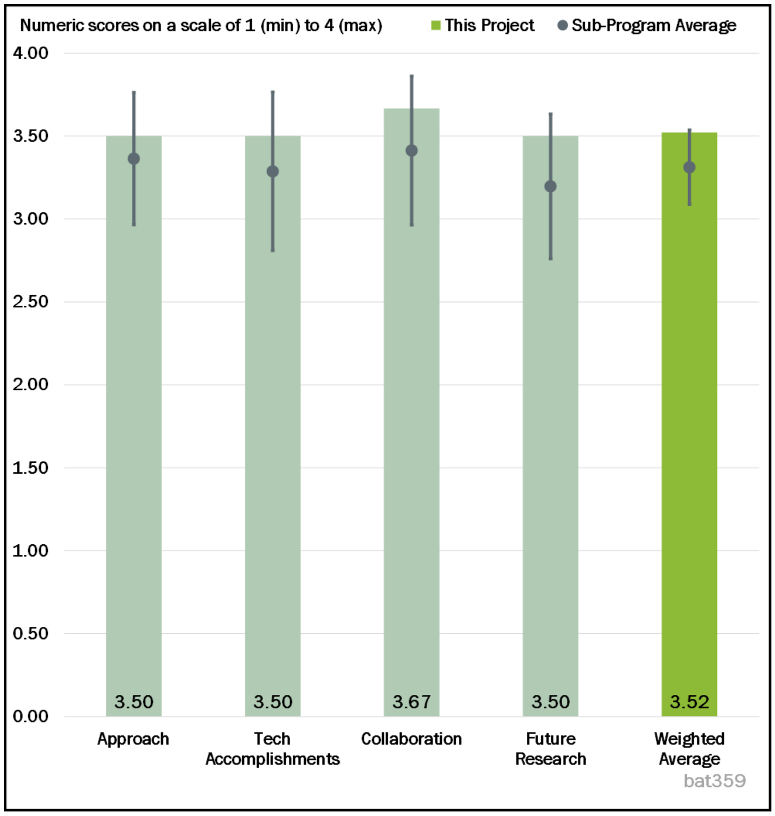

Figure 2-12 - Presentation Number: bat359 Presentation Title: Status and Challenges of Electrode Materials for High-Energy Cells Principal Investigator: Stanley Whittingham (Binghamton University)

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, the effort is well designed, feasible, and comprehensive. A clear scientific path toward overcoming obstacles for developing a cell that can deliver 500 Wh/kg was presented. Key issues such as cathode (high-Ni NMC) instability and safety are being addressed.

Reviewer 2:

The reviewer found the approach to improving the energy of high-Ni NMCs to be very good and commented that addressing irreversible capacity loss (ICL) and thermal stability are critical.

Reviewer 3:

The reviewer indicated that this presentation focused on one of the Keystone projects (Materials and Interfaces) in the Battery500 program, which has a goal of developing a Li-metal battery with either an NMC or a sulfur (S) positive electrode that can achieve 500 Wh/kg. This Keystone project is tasked with providing materials and chemistry support to other parts of the program, as well as to develop electrodes and find cell designs that will allow this goal to be achieved. Toward this end, this particular aspect of the work is directed toward coating NMC electrode materials to reduce reactivity in the environment and in the cell, understanding and mitigating first-cycle inefficiencies, and preparing high-capacity, high-Ni-content electrode materials that are not yet commercially available. The most challenging part of the project deals with addressing Li-metal cycling. While multi-faceted, the approach is highly focused and goal oriented.

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 focused approach has resulted in considerable progress for the program as a whole, judging from the results shown on Slide 7, which are impressive. A simple way to gain some energy density is to address the first-cycle irreversibility. Results reported here show what factors affect this and point to kinetic limitations near the end-of-discharge as the culprit. This is in agreement with earlier work by Abraham at ANL. The next step is to figure out what to do to overcome this. It is worth taking a look at the literature to see what has already been done along these lines; for example, partial low-level substitution with titanium (Ti) seems to reduce the inefficiency in NMC442 materials. The same goes for coating electrodes, where a lot has already been done.

Reviewer 2:
Excellent progress has been achieved this period. The reviewer noted that the potential source of first-cycle capacity loss in high-Ni NMC was identified (slow Li-ion diffusion), and a niobium (Nb) coating was found to significantly minimize this issue, resulting in a 5% increase in energy density of the full cell.

Reviewer 3:
There are good results for the year. The reviewer was not completely convinced that poor Li diffusion near full lithiation of NMC is the cause of the higher ICL. The improvement of ICL with calendaring and coating of the NMC seems to hint at another source of the issue.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Professor Whittingham has always exemplified the best in terms of collaborative research, and he continues that here.

Reviewer 2:
The reviewer commented that a synergistic and productive collaboration exists between Binghamton University and the Battery500 team members, as evidenced by recent publications.

Reviewer 3:
The Battery500 program, including this project, is highly collaborative and draws upon expertise from various National Laboratories and academic institutions. It appears to be carefully coordinated among the various institutions and is very goal oriented. The reviewer's only criticism here would be that it may be good to coordinate with other DOE programs as well since there is some overlap here with other projects (e.g., reducing Co content in NMCs). There has been a fair amount of work already dedicated to understanding and mitigating first-cycle inefficiencies in NMCs as well as their thermal behavior (also there is much research on this done outside the United States). PIs in this program should check the literature carefully to make sure they are not inadvertently duplicating previous work but are instead extending it.

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 planned work to reduce cobalt in nickel manganese cobalt aluminum (NMCA) and modify materials to increase energy density by addressing first-cycle inefficiencies and improving conductivities so that thicker electrodes can be used is sound. Likewise, it will be important to assess thermal stability of each modified material.

There has already been quite a lot of research on reducing cobalt, modifying NMCs to reduce first-cycle inefficiencies, and assessing thermal behavior of NMC-type materials in DOE-funded work, both past and present. The reviewer suggested that that work can and should be leveraged for this project.

Single-crystal materials may improve tap density and thus energy density, but it could come at the cost of rate capability (depending on size of crystal and whether modification to improve electronic conductivity is successful), so that is something to watch out for.

Reviewer 2:
The proposed research plans are methodical and address the major obstacles in developing a Li-metal battery. Efforts focus on pushing the limit of Ni content and reducing the concentration of Co. Plans also include developing thicker cathodes to increase specific energy and improving capacity retention.

Reviewer 3:
While there are good future plans, the reviewer thought that future work on high-Ni NMC will yield diminishing returns. The reviewer said that it is possible to get another 15%-20% energy at best; however, DOE has a “next gen cathodes” project that is concentrating on high-Ni NMCs. The reviewer wondered if there are other cathodes that the Battery500 could research (in addition to S, which is of course very high energy). This is not a comment specifically addressing Professor Whittingham’s research or future plans, just something for the entire program to consider.

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

Reviewer 1:
This effort is highly relevant to DOE’s goal of advancing Li-metal based battery technology. The PI has considerable experience in the field. In addition to Binghamton University’s present investigation, the PI brings valuable historical insight to the Battery500 Consortium.

Reviewer 2:
This work is highly relevant to the goals of the Battery500 program and that of DOE Vehicle Technologies Office (VTO) for EV batteries.

Reviewer 3:
The reviewer called the project highly relevant but indicated that the comment above about other cathode options also applies here.

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

Reviewer 1:
The project appeared to the reviewer to have sufficient resources to successfully meet the project objectives in a timely manner.

Reviewer 2:
The reviewer stated that resources are sufficient.

Reviewer 3:
Resources are sufficient.

Presentation Number: bat360
Presentation Title: Scale-Up Optimization and Characterization of High-Nickel Cathodes
Principal Investigator: Arumugam Manthiram (University of Texas at Austin)

Presenter

Arumugam Manthiram, University of Texas at Austin

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

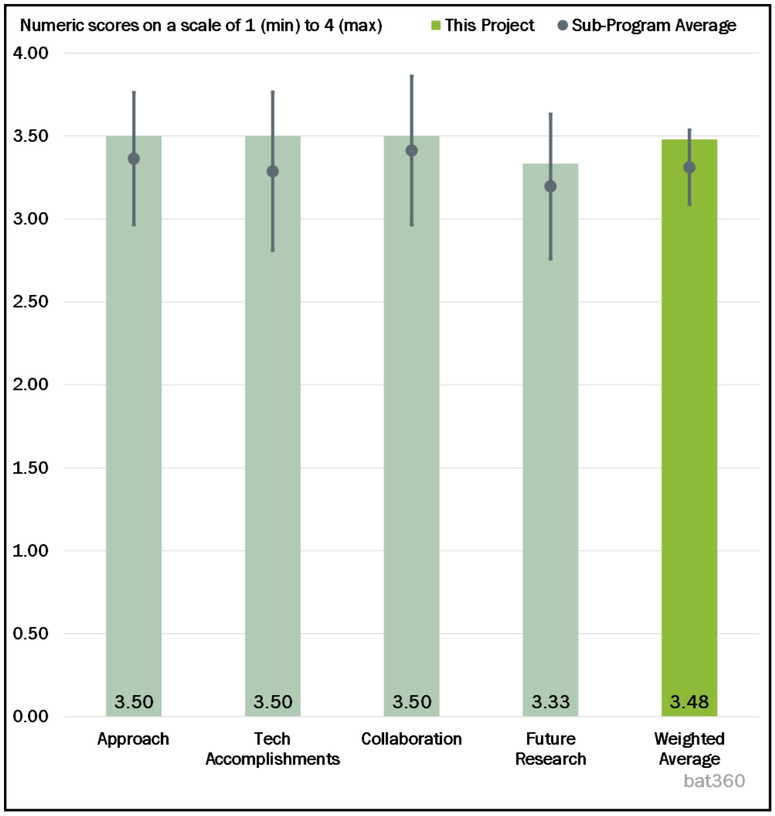

Figure 2-13 - Presentation Number: bat360 Presentation Title: Scale-Up Optimization and Characterization of High-Nickel Cathodes Principal Investigator: Arumugam Manthiram (University of Texas at Austin)

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 combination of experimental work on anode (lithophilic framework) and high-Ni NMC excellent.

Reviewer 2:
The approach is well developed and addresses the fundamental issues confronting the development of a stable, high-energy cathode material.

Reviewer 3:
The approach for this part of the Battery500 program is focused on synthesis and scale-up of new materials with higher Ni contents than what is commercially available and on methods for enabling stable cycling of Li. There is some overlap with other DOE projects, such as the low-Co cathode one, where the focus is more or less the same (less Co results in higher Ni content in many cases). The reviewer stated that some work is also dedicated toward improving cyclability of Li, which is key to making the two chosen Battery500 systems 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:
Progress here has been good. The PI observes that increasing Ni content in cathode materials comes with particular challenges, such as poorer cycling due to more pronounced phase changes, increased transition-metal dissolution, and particle cracking. Coating with polyaniline appears to alleviate some of these issues and improves cycling. The three-dimensional (3-D) lithiophilic framework on the anode side to allow more reliable Li cycling is an interesting idea and seems to show some promise. The PI will need to carefully assess the impact on energy density, according to the reviewer.

Reviewer 2:
Significant progress was achieved in the synthesis scale-up and characterization of high Ni-NMC cathodes, and the findings will help the Battery500 team move forward in their quest for a high specific energy cell. The major causes of cathode degradation were established by extensive experimentation (cell cycling) and the use of advanced characterization diagnostics.

Reviewer 3:
The reviewer asked why is the SEI growth shown on Slide 11 so non-linear? It looks like there is almost no change up to 500 cycles; then there is a huge change from 500 to 1,500. Also, the reviewer was confused about the milestones shown as completed on Slide 4 concerning Li-metal dendrite growth as the reviewer did not see any work presented there. Also, the second milestone concerning the impact of current density on Li-metal anodes is listed as completed, but this is also listed as a goal of future work on Slide 19.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer would like to see Professor Manthiram's team supply materials and possibly cells to other teams for independent evaluation.

Reviewer 2:
This project is part of the highly collaborative Battery500 program. This PI is tasked with providing new and promising materials to other PIs in the program although, as he states, scale-up is difficult for an academic laboratory. One possible solution is to utilize the Materials Engineering Research Facility (MERF) at ANL to do this; the reviewer's understanding is that there is no charge if the requester is from a National Laboratory or university. Likewise, scale-up could be contracted out to other facilities with pilot lines although there will likely be charges for this. While, in general, collaboration and coordination are very good in the Battery500 program, there are other efforts within DOE projects that may be relevant to this project (e.g., a low-Co cathode program) and PIs should do more to reach out to researchers in these programs.

Reviewer 3:
Productive collaboration exists between this project and other member's projects of the Battery500 team. This includes Brookhaven National Laboratory (BNL) (structural and morphological characterization of high-Ni NMC), Binghamton University (thermal stability studies), INL (electrochemical analysis), and PNNL (evaluation of electrolytes with cathodes).

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 particularly liked the Li-free cell work planned for 2021. This is the ultimate goal of cells using lithiated cathodes.

Reviewer 2:
Future work is devoted to further electrochemical characterization of cells containing Li anodes and high Ni-content cathodes, more work on the lithiophilic hosts for the anodes, use of electrolyte additives, and attempting "anode-free" cells. The plan seemed appropriate to the reviewer.

Reviewer 3:
The future planned activities are sound and are a logical extension of recent findings. They address the challenge of assessing the long-term stability of NMC cathode materials when using a full-cell design and an anode that has limited cycle life.

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

Reviewer 1:
This project is highly relevant to DOE objectives. It is in line with the push toward higher cell specific energy and a reduction of costly raw materials, such as Co.

Reviewer 2:
This work is highly relevant to the goals of the Battery500 program and those of DOE-VTO with respect to electric vehicle batteries.

Reviewer 3:
The reviewer found the project to be highly relevant.

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 appears to have the necessary resources to complete the effort on schedule.

Reviewer 2:
There are appropriate resources.

Reviewer 3:
Resources are adequate. The reviewer suggested that the PI should reach out to MERF or other facilities for scale-up.

Presentation Number: bat361
Presentation Title: Understanding Electrode Interface Through Cryogenic Electron Microscopy
Principal Investigator: Yi Cui (Stanford University/SLAC)

Presenter

Yi Cui, Stanford University/SLAC

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

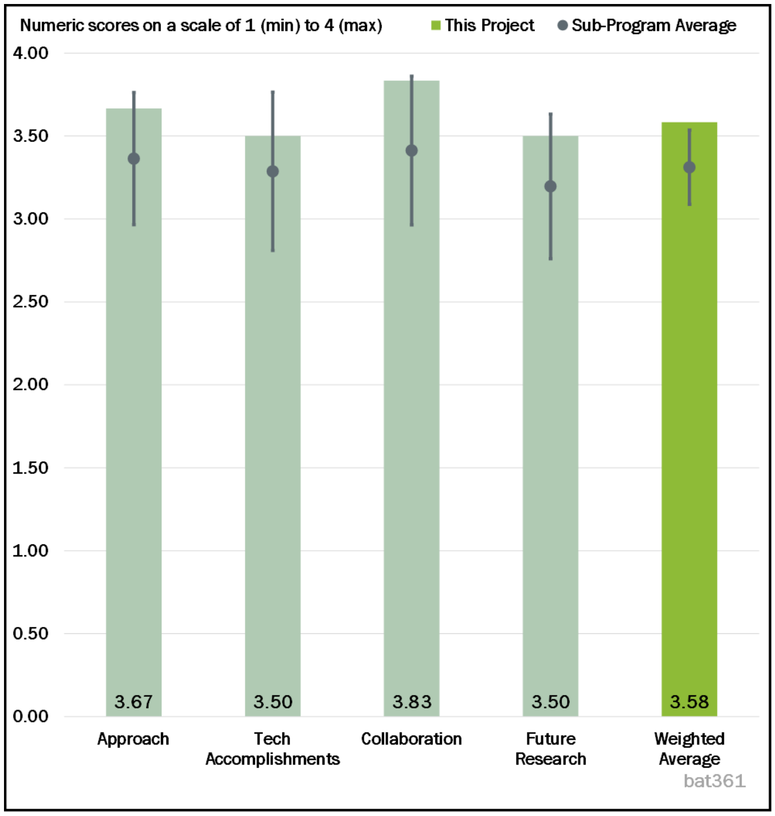

Figure 2-14 - Presentation Number: bat361 Presentation Title: Understanding Electrode Interface Through Cryogenic Electron Microscopy Principal Investigator: Yi Cui (Stanford University/SLAC)

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 the approach to be very imaginative and exploratory, just what is needed in a challenging and revolutionary program like Battery500.

Reviewer 2:

The project is well defined and very well coordinated with the rest of the Battery500 effort. The PI is very good and has done interesting work. Both the host structure data and the cryogenic electron microscopy (cryo-EM) data look promising and interesting.

Reviewer 3:

The team has an excellent approach in addressing the issues associated with the use of Li-metal anodes in high-energy battery cells. On the material design and synthesis side, 3-D Li-metal host composite anodes and interfacial- modification techniques are developed. On the characterization side, cryo-EM is used to investigate SEI on Li metal at atomic resolution. Together, the project effectively contributes to the goal of the Battery500 program in developing stable and high-capacity Li-metal anodes for high-energy batteries.

The reviewer indicated that one thing to consider is the relevance of cryogenic electron microscopic observation made under very low temperatures to what occurs in a practical cell operating under realistic cycling conditions.

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:
Excellent progress was made here. The team designed and synthesized 3-D Li-metal composite anodes to accommodate volume expansion and contraction. The clear observation of SEI nanostructure under cryo-EM is rather impressive. The effect of the fluoroethylene carbonate (FEC) additive on the properties of SEI formed was elucidated, and the evolution of SEI was also investigated. The team was incredibly productive, with an impressive body of publications published in high-impact journals.

It was not clear to the reviewer how much of the cryo-EM studies were carried out in situ or in operando. There is a bit of dilemma here as, on one hand, SEI observation needs to be made in situ/in operando to be relevant but on the other hand, the low-temperature conditions under cryo-EM is likely to cause significant alteration in SEI behavior. The reviewer would like to get the team's opinion on this.

Reviewer 2:
The reviewer commented that the approach is somewhat difficult to evaluate as Professor Cui tends to show results from many years ago mixed in with his results from 2019, but still very good progress. One question that might be worth trying to answer is if the Li-metal SEI grows with time at a fixed potential. If it does, then it is clearly not passivating.

Reviewer 3:
The data looked very good to the reviewer. While the reviewer saw the connection between SEI structure and efficiency, the reviewer wondered how this information will be used to go from 95% to 99.9%. Has the PI looked at—or is planning to look at—the higher (99+% efficiency) that appears to be the focus among other PIs in Battery500? It will be good to look at the latest materials. The reviewer noticed that in the next talks that this is happening so maybe the project has a plan already in place.

The reviewer was a bit concerned about the sudden lower efficiency on the host structures. Please make sure this is not a soft short as this is possible. The reviewer worried that the host will lead to deposition at the surface (closest to the cathode) and lead to dendrites. The PIs should consider seeing what the charge rate limit is before dendrite formation and quantify this, which will really help the community. Also, the reviewer expressed worry that 3-D constant currents (CCs) with a liquid will add more surface area for more SEI formation and less efficiency.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Collaboration across the team in the Battery500 program and Stanford Linear Accelerator Center (SLAC)/Stanford University is excellent.

Reviewer 2:
This reviewer emphasized that the whole program is very well coordinated. The reviewer said that it was Impressive to see this in such a large program.

Reviewer 3:
There are very good 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:
Overall, the proposed future work is logical toward addressing the barriers in Li-metal based batteries.

Reviewer 2:
The reviewer liked all the tasks, which addressed the reviewer's previous questions.

Reviewer 3:
The reviewer wondered if a team in the Battery500 program should start to investigate in-situ dendrite diagnostics. There is yet to be an electrolyte, whether it is ceramic, polymer, block co-polymer, etc., that does not form dendrites under some conditions. The reviewer suspected that the car companies would be much more likely to use a technology like Li-metal cells if there were a way (using coulombic efficiency, for example) to detect the beginnings of dendrite formation and growth.

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

Reviewer 1:
The use of Li-metal anode is an important step toward achieving the Battery500 goals. Current technology faces significant challenges in terms of low CE and poor cycling life of Li-metal anodes. By developing more efficient 3-D composite Li anodes and engineering a more stable SEI layer, this project is very relevant to the overall DOE objectives.

Reviewer 2:
The reviewer found the project to be highly relevant.

Reviewer 3:
According to the reviewer, Li-metal is very relevant.

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

Reviewer 1:
It was unclear to the reviewer how much funding this project receives, so it was difficult to judge whether or not enough resources are available. However, the overall Battery500 program has sufficient resources.

Reviewer 2:
There are appropriate resources, according to the reviewer.

Reviewer 3:
The project has good use of funds.

Presentation Number: bat362
Presentation Title: Lithium-Metal Anodes: Problems and Multiple Solutions Based on Hosts, Interphase, and Electrolytes
Principal Investigator: Jason Zhang (Pacific Northwest National Laboratory)

Presenter

Jason Zhang, Pacific Northwest National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

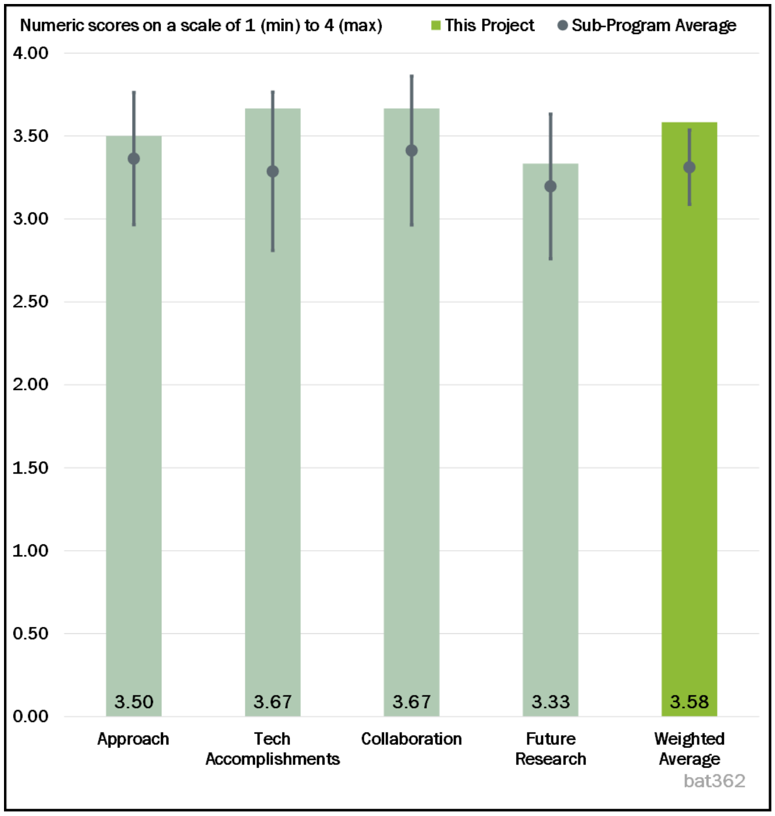

Figure 2-15 - Presentation Number: bat362 Presentation Title: Lithium-Metal Anodes: Problems and Multiple Solutions Based on Hosts, Interphase, and Electrolytes Principal Investigator: Jason Zhang (Pacific Northwest National Laboratory)

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 project is sophisticated, comprehensive, and well designed. It focuses on shedding light on a major obstacle impeding the development of a high-energy-dense battery: the reactivity of Li metal with traditional electrolytes.

Reviewer 2:
The team proposed highly effective approaches to address the barriers. The team proposed innovative electrolytes, such as localized high-concentration electrolytes (LHCE), and 3-D lithiation hosts to mitigate poor CE and large volume change associated with Li-metal anodes.

Reviewer 3:
Novel electrolytes are almost certainly needed for Li metal. The reviewer wondered if there is a better way to screen them other than cycling. Perhaps leakage current can be monitored at a fixed potential or the thickness of the SEI as a function of time at a fixed potential can be measured to determine if the Li-metal SEI is stable.

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's findings have significantly expanded the knowledge of ether-based electrolytes and have provided new perspectives of electrolyte design for LI-metal batteries. LHCEs were shown to have a high cycling efficiency (99.5%) in pouch cells.

Reviewer 2:
Using innovative LHCEs, the reviewer noted that the team made excellent progress to improve CE to 99.77% and reduced Li-volume change by four times in a full cell with a high-Ni NMC811 cathode. In addition, the team also demonstrated the feasibility of an anode-free Li rechargeable cell, albeit with limited cycles. Using innovative surface-characterization tools, such as cryo-EM, the team characterized the cathode-electrolyte interphase (CEI) and SEI compositions. These results should enable the team to improve the electrolytes to meet the Battery500 goals.

Reviewer 3:
Some of the results (Slide 14 with 1.5 mAh/cm^2 cathode and 10 mAh/cm^2 anode) are not representative of a commercial cell, but overall, it is well done. Also, one needs to remember that 99.3% CE means the cell with twice the excess Li is dead in 100 cycles or so. The reviewer said to be careful to keep the final goal in mind: 99.9% CE or higher.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The PI assembled an excellent team, with a clear description of the role of each team member.

Reviewer 2:
There has demonstrated significant and valuable collaboration with such organizations as Stanford University, Texas A&M University, University of Texas, and University of California at San Diego.

Reviewer 3:
There are very good collaborations. The reviewer proposed an independent evaluation of their LHCE costs and commented that, while there have been results for several years now, cost has not been discussed other than at a very high level.

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 efforts continue with a well-designed, comprehensive plan. The team will continue to investigate new formulations of LHCEs to increase affordability and improve safety. Efforts will also be devoted to investigating the optimized electrolytes.

Reviewer 2:
The reviewer proposed an independent evaluation of their LHCE costs and commented that, while there have been results for several years now, cost has not been discussed other than at a very high level.

The project needs some way to quantitatively predict whether an electrolyte-anode combination will produce dendrites or not and they need to be detected early.

Reviewer 3:
The project is 70% completed, and the project team demonstrated feasibility of achieving high CE using Li-metal anodes. However, the cell parameters used in those high CE cells, such as the loading of ~1.5 mAh/cm^2 with excessive electrolyte at a slow rate of C/10 and excess Li metal, will not enable reaching the 500 Wh/kg goal. The reviewer commented that efforts should not be devoted to reducing the cost of electrolyte (as was proposed) until the team can demonstrate high CE in cells capable of more than 500 Wh/kg. The team also needs to provide calendar life and low-temperature data using the LHCE.

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

Reviewer 1:
The project is highly relevant, according to the reviewer.

Reviewer 2:
This effort has developed knowledge that is useful in understanding and enabling the use of Li-metal in liquid-electrolyte systems. The knowledge gained could lead to a much higher energy density and consequently a lower cost per kilowatt-hour battery than today's state-of-the-art.

Reviewer 3:
The Li metal-based project is relevant for achieving high energy density required for the Battery500 program. However, in addition to CE, the team needs to address Li dendrites and interface issues associated with Li-metal anodes.

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

Reviewer 1:
The resources appeared sufficient to the reviewer, who noted that considerable progress has been made.

Reviewer 2:
There are appropriate resources.

Reviewer 3:
Resources are sufficient, but it was not clear to the reviewer that, with the remaining 30% of funds, the team will be able to demonstrate high CE using 500 Wh/kg cell parameters in pouch cells, protection layers to mitigate Li dendrites, and 3-D hosts to mitigate the interface issues.

Presentation Number: bat364
Presentation Title: Surface Coating for High-Energy Cathode
Principal Investigator: Jihui Yang (University of Washington)

Presenter

Jihui Yang, University of Washington

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

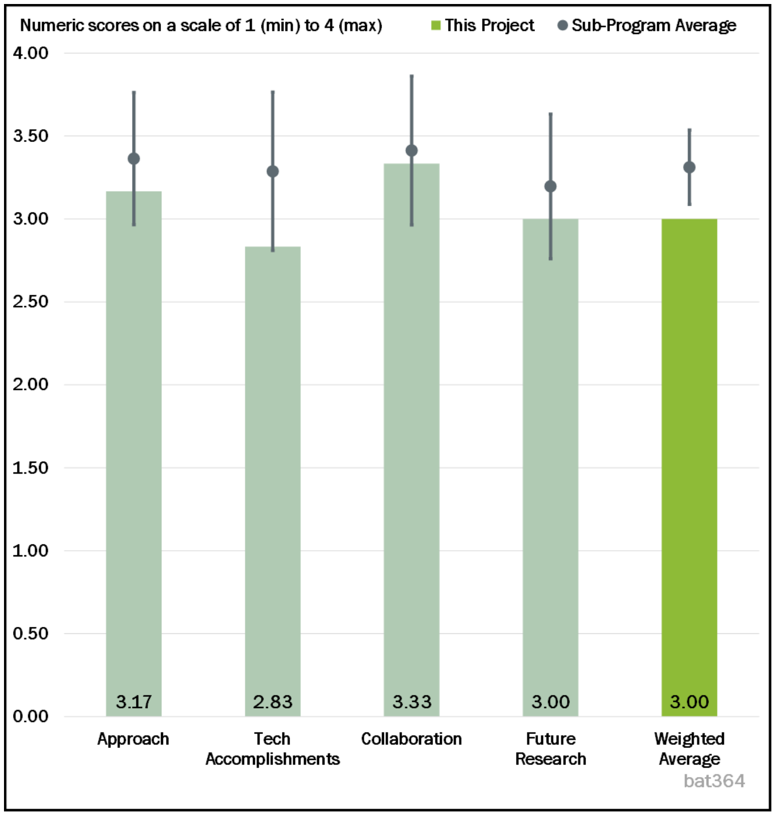

Figure 2-16 - Presentation Number: bat364 Presentation Title: Surface Coating for High-Energy Cathode Principal Investigator: Jihui Yang (University of Washington)

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:

Work on this project is directed toward conductive coatings on Ni-rich NMCs and separators to ameliorate reactions with electrolytic solutions and to enable Li-metal cycling. This should enable cells with specific energies greater than 350 Wh/kg to be achieved, thus is worth pursuing.

Reviewer 2:

The lithium borate ($LiBO_2$)/LiF chemical coating approach for NMC 811 is a step in the right direction to improve stability at high oxidation voltage. The reviewer would like to know if the process can be scalable in principle.

Surface coating of separators with solid electrolytes, such as lithium aluminum titanium phosphate (LATP), is promising and has certain specific advantages. The reviewer wondered if this contributed to the increase in the interface resistance between the Li-metal and the separator, which could lead higher cell over-potential at high currents.

Doping NMC 811 with Al is a pretty good approach. Does the Al stay at the surface or occupy transition metal (TM) sites of the cathode? A few more doping levels should be tried to optimize the performance as only 1 mole% is shown.

Reviewer 3:

Coating and doping are very effective means to improve high Ni-cathode stability, but Al doping has been demonstrated by many for a while. It was not clear to the reviewer why this project is looking at this when others already have done it. Regarding the coating work, the reviewer really liked that the team used simple, wet-chemical means to coat the lithium diofluoro (oxalate) borate (LiDFOB). The reviewer was unsure why the project team is moving toward an expensive ALD technique and inquired about more cost-effective methods that can be scaled.

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 wondered why there is only a very incremental improvement in the performance between coated versus uncoated NMC811 (see, for example, Slide 8). How significant is the reduction of polarization from coated versus uncoated? The basis for dq/dv peak comparison between coated and uncoated needs to be explained. How was peak position chosen to compare polarization difference?

The effect of Al doping on reduced cracking of NMC811 is clearly demonstrated. A mechanistic investigation is worthwhile.

How did the presenter know that $LiBO_2$ is shown from XPS on Slide 7? Only the B1s peak is shown. More information is needed to ascertain that it is $LiBO_2$.

Reviewer 2:
NMC-811 was coated with $LiBO_2$ and LiF by thermally decomposing LiDFOB. It was hard for the reviewer to tell the nature of the coating (e.g., whether it is conformal and pinhole-free) from the images that were provided. Nevertheless, the coatings did seem to result in some improvements although it is not clear why. In particular, it is not obvious why a coating would suppress the second hexagonal – third hexagonal phase transition at high potentials or improve its reversibility. It would be good to try to understand this.

The collaboration with Sun's group at Hanyang University on Al-substituted NMC811 also was fruitful; the substituted variant performed better and seemed to reduce cracking, which exacerbates fading. Another advantage to the Al-substitution may be better thermal stability although this was not explicitly addressed in the presentation. Coating separators with LATP also seemed to improve cycling. Again, it was not clear to the reviewer what exactly the mechanism is. LATP in contact with metallic Li is known to undergo reduction and becomes electronically conductive due to the presence of trivalent Ti. How big an effect this is and whether it is a problem will depend a lot on the thickness of the coating. There are plans to make the coatings thinner, and it is possible that problems will be revealed once this is done. In summary, modifications made to materials and cells all seem to have good effects, but the explanation of why is lacking. Understanding the mechanisms will help the PI refine the materials and processes to make them more effective.

Reviewer 3:
The reviewer was not sure what is novel here and suggested that the team try a bunch of coatings or a bunch of dopants, or work on why Al doping is effective.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This is part of the highly collaborative Battery500 program. It is good to see some collaboration outside this program (that with Sun at Hanyang University) as well.

Reviewer 2:
The group is collaborating with PNNL on cell fabrication and testing and University of Texas at Austin (UT-Austin) and State University of New York at Binghamton on synthesis and characterization of high-capacity NMC811 cathodes.

Reviewer 3:
There is good coordination to standardize protocols and data with the Battery500 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:
ALD coating of NMC811 is relevant and provides a good basis for comparison with a chemical coating.

Reviewer 2:
Plans are to investigate methods to coat LATP on separators using ALD and spray coating and optimize the coatings. Coatings on the anode side may become electronically conductive more rapidly if thinner, however. It would be good to see some investigation into the mechanisms of how these coatings work, which can be part of the optimization.

Reviewer 3:
What is the team going to do with ALD that others are not already doing? Is the team able to do new chemistries or demonstrate scale-up? There are good results with the wet-chemistry method so why not work on low-cost methods to coat high-nickel materials?

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

Reviewer 1:
This work is relevant to the goals of the Battery500 program, one of which is to enable usage of Ni-rich NMCs in high-energy batteries. These goals are also relevant to DOE-VTO objectives for electric vehicle batteries.

Reviewer 2:
Developing high-energy-density batteries with specific capacity in the range of 400 Wh/kg or beyond is key to DOE's electrification goal. This project is directed toward developing high-energy-density Li-ion cells.

Reviewer 3:
High-Ni cathode materials are a critical component to achieve DOE energy-density roadmap targets for automotive applications. The reviewer asserted that ways to achieve long cycle life and calendar life need to be found.

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

Reviewer 1:
Resources are sufficient, according to the reviewer.

Reviewer 2:
Resources seem sufficient for this effort.

Reviewer 3:
There are adequate resources.

Presentation Number: bat365
Presentation Title: Stabilizing Lithium-Metal Anode by Interfacial Layer
Principal Investigator: Zhenan Bao (Stanford University/SLAC)

Presenter

Zhenan Bao, Stanford University/SLAC

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

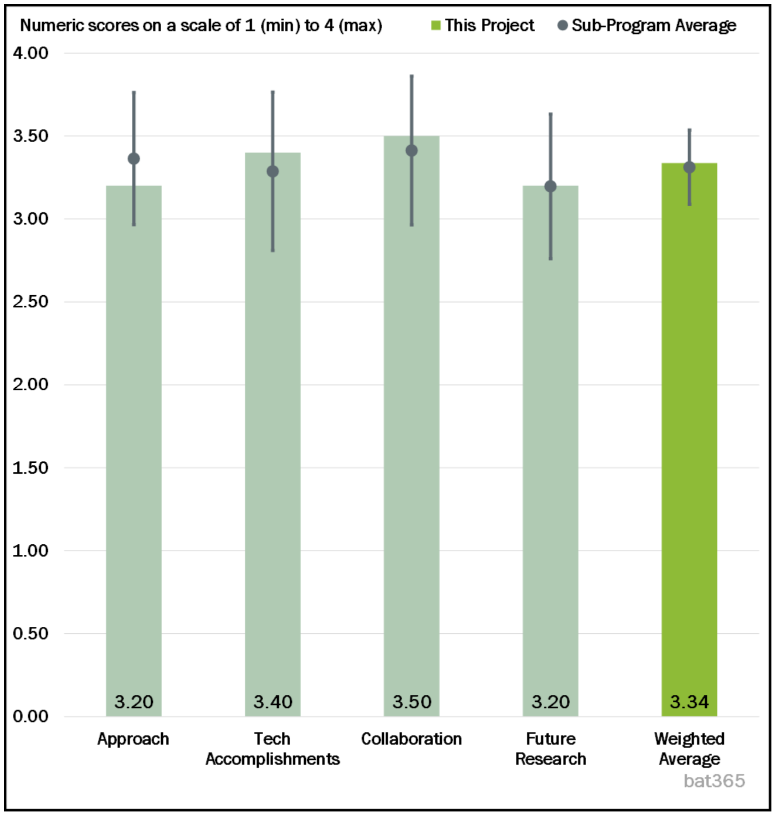

Figure 2-17 - Presentation Number: bat365 Presentation Title: Stabilizing Lithium-Metal Anode by Interfacial Layer Principal Investigator: Zhenan Bao (Stanford University/SLAC)

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 idea of adding polymeric layers with dynamic crosslinks to enable stable electrodeposition of Li is novel. The work covers diverse research activities ranging from polymer design to cell testing. The project is well designed and well planned.

Reviewer 2:

The reviewer understood the need to try all possible solutions to stabilize the Li-metal interface; thus, this project makes sense. An artificial SEI is very difficult to design, but so is every other solution. The reviewer thought that the focus has to be on first achieving a competitive CE and, somehow, convincing the team that a "soft" polymer will ever be able to stop dendrite formation and growth. Liquid electrolytes are certainly the most "flowable" and "conformable" electrolytes available, and yet they suffer dendrites.

According to the reviewer, this is an approach that can work. The Bluecar Li-metal batteries used by Bolleré have apparently lasted thousands of cycles with a polyethylene oxide (PEO) -based electrolyte due to pressure being applied to the cells. This might be a solution that could be understood in detail and designed into cells and modules.

Reviewer 3:

The use of a flowable polymer depending on the needs of the system is an important step of making Li-metal-based cells practical. The performance data shown are impressible, going out to 100-200 cycles. It would be more interesting to go to 1,000 cycles. How does the polymer affect energy density and retention?

Reviewer 4:
The overall approach is to use polymers with various desirable attributes as interfacial layers or electrolytes to enable higher efficiency and more stable Li-metal plating and stripping. A focus is to understand chemical and mechanical aspects of the polymer layer on the influence of Li-metal electrodes. The polymers are characterized using a variety of methods, and simulation and theory are used to more fully understand the mechanics of Li plating within these systems. The technical approach is sound and will continue to result in interesting science. A score of 3 was given instead of higher simply because it is unclear whether this is the absolute best strategy to enable Li metal batteries even though this reviewer found it to be a reasonable direction to pursue.

Reviewer 5:
Regarding battery life, the reviewer commented that improvements in cycle stability were demonstrated, but not a dramatic improvement. The team met the soft milestones of 20% enhanced cycle-life performance. The best performance shown in the slide was 250 cycles. The Stanford group only cycles enough to show improvement, so the reviewer did not know when or how the battery fails.

With regard to specific energy, 500 Wh/kg was stated as an objective, but specific energy was not determined for any of the cells evaluated.

Nonetheless, the reviewer indicated that about six different polymers were synthesized and tested as protective coatings at the Li-metal interface over the last 4 years. Different polymers were designed with clear hypotheses for how the properties were expected to improve the cycling performance. During the most recent year, work focused on the dynamic, single-ion network, polymers with different cation (Al, Si, and boron) and F substitutions. This was a creative development in polymer synthesis and determination of a unique combination of properties of a polymer electrolyte materials (flowable, near single ion, Li stable, solvent barrier) tunable with the cation and F substitutions.

Milestones also included investigation of 3-D host framework for the Li anode, but this was reported in a different presentation (BAT361). A number of the slides were identical for the two presentations, which confuses the assessment.

Milestones, which included adoption of the Battery500 protocols for Li architectures and quantifying the inactive Li, were listed in the slides. Results toward these milestones were not presented. Various researchers have advocated for using thin Li anodes to quickly and quantitatively determine the amount of Li lost due to physical isolation and electrolyte reaction to for SEI products. At first, the Li||Cu test cells suggested that this was being followed. Reading the procedures in publications, however, was quite confusing and a thick Li layer was likely deposited onto the Cu. So, the cause for sudden deterioration of the cells remains unclear, as is the relative amount of reacted Li versus physically isolated but unreacted Li metal, which was not determined.

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:
All milestones are completed or on track. There have been eight publications since the start of FY 2019, many in high-profile journals. The development of the aluminate salt for dynamic-bonding networks was interesting to the reviewer, and Li-metal results are promising, particularly the cycling. The reviewer also appreciated the nice combined experimental and simulation theory approach to understanding transport mechanisms. However, the interfacial resistances are quite large (approximately 700 ohms, assuming these are about 1 cm^2 electrodes) and conductivities quite low (10^{-4} Siemens [S]/cm at room temperature [RT]).

Reviewer 2:
There are several aspects to the proposed work: design of novel polymers with dynamic crosslinks, characterization of the polymer, application of the polymer to Li metal, and cell testing. The team has used

Battery500 protocols to test the efficacy of their materials, which is notable. The addition of modeling to the project is an excellent development. The PI presents considerable evidence that addition of the designed polymeric layers affects the morphology of deposited Li and cycle life. The differences in Li morphology seen by scanning electron microscopy (SEM) are striking. The reviewer hoped that, with time, the PIs will provide more direct evidence for the proposed hypotheses. The polymers appear to have functional groups that will likely react with Li metal, especially during prolonged cycling. Data of the kind presented on Slide 7 should be presented with error bars. The reviewer did, however, appreciate the error bars on Slide 8.

Reviewer 3:
Progress in designing, synthesizing, and evaluating the properties of novel polymer, Li-ion conductors is impressive. Unfortunately, in most cases the improvement in the cycling stability of the Li metal was modest. The investigators acknowledged the challenge posed to stabilize the Li metal and suggest that in future, combined approaches, polymer coating and a 3-D scaffold would be applied to see additional improvement.

The artificial SEI coatings captured most of the properties that are believed to be needed for a successful SEI. It was clear to the reviewer that, from the Li microstructures with distinct rounded particles of Li, the reaction with the electrolyte had not been well passivated. Additional interface area was created as the Li was plated and stripped.

Reviewer 4:
The PI explained the polymer-design principles and the basis for them very clearly. Progress was clear, but the reviewer was unsure how the modeling will impact further development of the polymer.

Reviewer 5:
The team reported 96.5% CE on Slide 16 so that is 60-70 cycles before a 2X Li is gone. The reviewer also suggested that the teams focus on one problem at a time (Li-metal SEI) instead of both that SEI and a 3-D host for Li.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The PI collaborates well with team members, especially at Stanford and the Stanford Synchrotron Radiation Light Source.

Reviewer 2:
There are many joint publications with other laboratories at Stanford and within the Battery500 project and very strong collaborations.

Reviewer 3:
The reviewer commented that the collaboration and coordination was very nicely integrated with the rest of the team and its goals.

Reviewer 4:
Collaborations are entirely with other investigators at SLAC. This has been productive and brought a wide range of modeling and characterization methods to the studies and publications. Collaboration with other Battery500 investigators seems to be missing, as they are not co-authors on any cited works.

Reviewer 5:
The reviewer was not sure how the collaborators worked together and who contributed what. The presentation came across as a single PI.

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 follows directly from the accomplishments described. It follows logically from prior work and is aimed at meeting overall programmatic needs.

Reviewer 2:
The PI showed how the results will be used in the further development of the polymer and what the remaining obstacles are. According to the reviewer, the PI's approach to the obstacles was well thought out.

Reviewer 3:
A reasonable continuation of work is conveyed although only briefly.

Reviewer 4:
Future work is directed toward further development of artificial SEIs, but it is vague and specifics were not given. Presumably, the plan is to further design and synthesize polymer coatings to act as SEI layers on the Li. The polymers synthesized to date have novel properties so additional work in this direction may be fruitful. It only takes one new material to change the future of Li-metal batteries.

Additional plans are to combine these artificial SEIs with 3-D Li host and high-performance electrolytes. Without further explanation, the reviewer remarked that there is an assumption that the expectation is for the improvements to be additive.

Reviewer 5:
As noted above, the reviewer would possibly de-emphasize the 3-D host work here as other teams are pursuing that. Instead, focus on achieving a competitive CE and, somehow, convincing the team that a "soft" polymer will ever be able to stop dendrite formation and growth, or consider some other way to control dendrites.

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

Reviewer 1:
The reviewer enthused, "Absolutely!" Solutions to the Li deposition (dendrite formation) are critically needed for the project to succeed.

Reviewer 2:
Enabling Li-metal electrodes is a key target of DOE efforts right now. This work is clearly relevant toward that goal.

Reviewer 3:
The project is highly relevant to stabilizing the Li-metal interface.

Reviewer 4:
An important objective of the DOE program is to enable high-specific-energy rechargeable batteries; enabling Li metal is the most promising approach for meeting this objective. The work of the PI is clearly aimed at meeting this objective.

Reviewer 5:
This is relevant to finding a practical way to stabilize the Li metal within the liquid-electrolyte battery design.

If the artificial SEI coatings were more robust, they might have found a solution to a profound challenge for achieving Li-metal batteries.

There was a good effort and modest improvement.

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

Reviewer 1:
The work reported here and in the cited publications was thorough and detailed.

The VTO support was coordinated with National Science Foundation programs lead by other Stanford co-authors.

Reviewer 2:
Resources are sufficient to meet milestones in a timely fashion.

Reviewer 3:
The resources applied to the problem at hand seemed to be reasonable.

Reviewer 4:
According to the reviewer, there are appropriate resources.

Reviewer 5:
It was not entirely clear to the reviewer how much funding is directed toward this specific project within Battery500, but it appears sufficient given the outcomes.

Presentation Number: bat366
Presentation Title: Advanced Imaging and Quantitative Characterization of Lithium-Metal Anode and Its Solid Electrolyte Interphase (SEI)
Principal Investigator: Shirley Meng (University of California at San Diego)

Presenter

Shirley Meng, University of California at San Diego

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

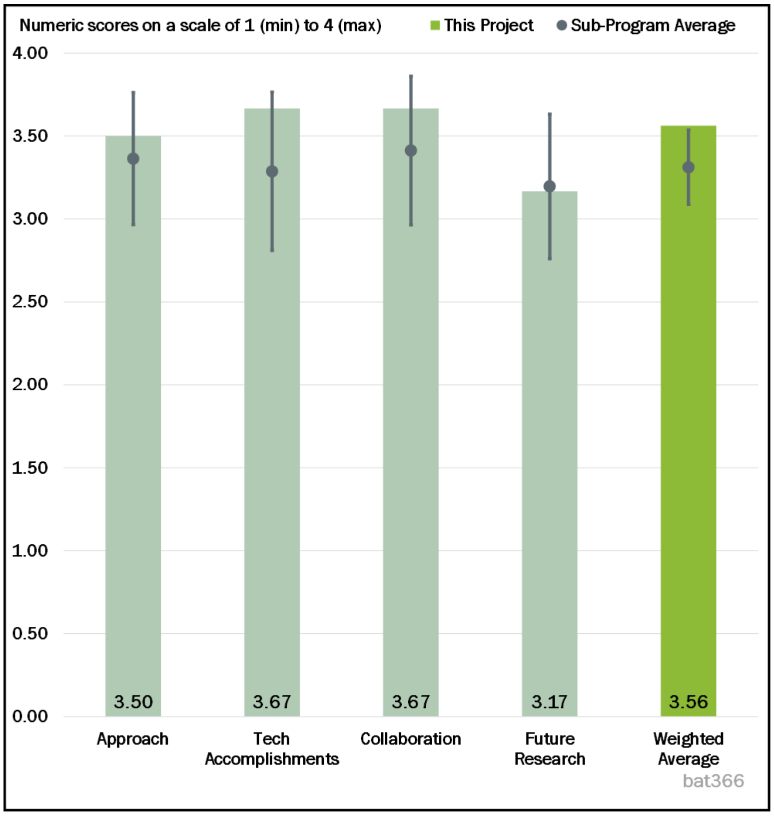

Figure 2-18 - Presentation Number: bat366 Presentation Title: Advanced Imaging and Quantitative Characterization of Lithium-Metal Anode and Its Solid Electrolyte Interphase (SEI) Principal Investigator: Shirley Meng (University of California at San Diego)

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, the PI and team have provided extraordinary diagnostic support to the Battery500 team toward a mechanistic understanding of the Li-metal nucleation and growth and the SEI formation. Several state-of-the art techniques, such as cryogenic transmission electron microscopy (cryo-TEM), titration gas chromatography, and X-ray micro-computerized tomography (CT), are used for characterizing Li metal.

Reviewer 2:

The approach of this project is to combine microscopy, tomography, diffraction, molecular dynamics (MD) simulations, and quantitative measures of Li plating and stripping to understand the Li-metal SEI and its influence on performance. The reviewer found the approach to be systematic and well executed, among the best studies on Li-metal stripping and plating.

Reviewer 3:

The main challenge in the Battery500 effort is the stability of the Li metal. This approach directly addresses the understanding of the Li-degradation processes. Also, 3-D electrode for Li is proposed as a solution. The main diagnostic tool is cryo-EM. The reviewer was unsure if the program needs multiple people using this tool.

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 all milestones have been completed or are on track, and there are four publications, with two more submitted or in preparation, including in *Nature*. The studies are exhaustive, with new insights into Li-metal nucleation, a key account of dead Li and its influence on coulombic efficiencies in a variety of electrolytes, and initial promising studies on 3-D electrodes. This is an impressive amount of high-quality work that provides a deep understanding for the rest of the field.

Reviewer 2:
Evolution of Li-metal morphology and the SEI is pretty much coupled and to a large extent dictates the performance and cycle life. The PI and team have developed several strategies to mitigate dead Li-metal formation, but the focus of this work is developing various methods to characterize Li-metal and CEI to study their composition and morphology during stripping and plating. The team has demonstrated excellent progress in achieving its objectives, and the reviewer indicated that the results will lead to improvements in the CE and cycle life of high energy-density LIBs.

The reviewer was interested to know if the 3-D current collector approach can be scalable and, if so, what the fabrication methods are. MD simulation of Li-metal nucleation and comparison with cryo-TEM is a robust approach. Developing a multi-scale modeling effort for the 3-D current collector to map the heterogeneity of current distribution and electric field would be a good approach to validate X-ray CT results.

Reviewer 3:
The PI has a long history of excellent work, combining multiple tools to understand phenomena. The PI has some unique cryo-EM results and insights. The reviewer also liked the 3-D electrode studies. The reviewer was not sure the overall concept will be the answer for moving forward, but it is interesting. The 3-D electrode effort would benefit greatly from some electrochemical engineering modeling.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer was very impressed with the collaborative nature of all Battery500 projects, including this one.

Reviewer 2:
The PI has established a number of valuable constructive collaborations.

Reviewer 3:
According to the reviewer, there is a very balanced team and collaboration between the characterization team to help the cell assembly and the cathode development team to achieve the energy density and cycle-life targets.

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 work looks promising and, if successful, would provide breakthroughs in making the Li-metal stable in liquid electrolytes and better control of SEI.

Reviewer 2:
The project is a reasonable extension of current work although only briefly highlighted.

Reviewer 3:
The PI is planning to continue current efforts. There are not a lot of details.

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

Reviewer 1:
The reviewer stated that the work supports the Battery500 goal of approaching 500 Wh/kg for 1,000 cycles. To achieve this target requires stabilization of Li-metal. A mechanistic understanding of the evolution of Li-metal morphology upon cycling is critical for optimal CE and cycle life for EVs.

Reviewer 2:
The PI is attacking the crucial programmatic challenge, which should significantly reduce the cost of batteries if successful.

Reviewer 3:
Enabling Li-metal electrodes is a key DOE-VTO goal, and this project directly supports that mission.

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 PI seems to have sufficient resources.

Reviewer 2:
Resources are adequate.

Reviewer 3:
The resources appear sufficient given the outcomes although it was not clear to the reviewer how much Battery500 funding went directly to this project.

Presentation Number: bat367
Presentation Title: Characterization Studies on Li-Metal Anode and High-Ni Cathode Materials
Principal Investigator: Peter Khalifah (Brookhaven National Laboratory)

Presenter

Peter Khalifah, Brookhaven National Laboratory

Reviewer Sample Size

A total of two reviewers evaluated this project.

Project Relevance and Resources

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

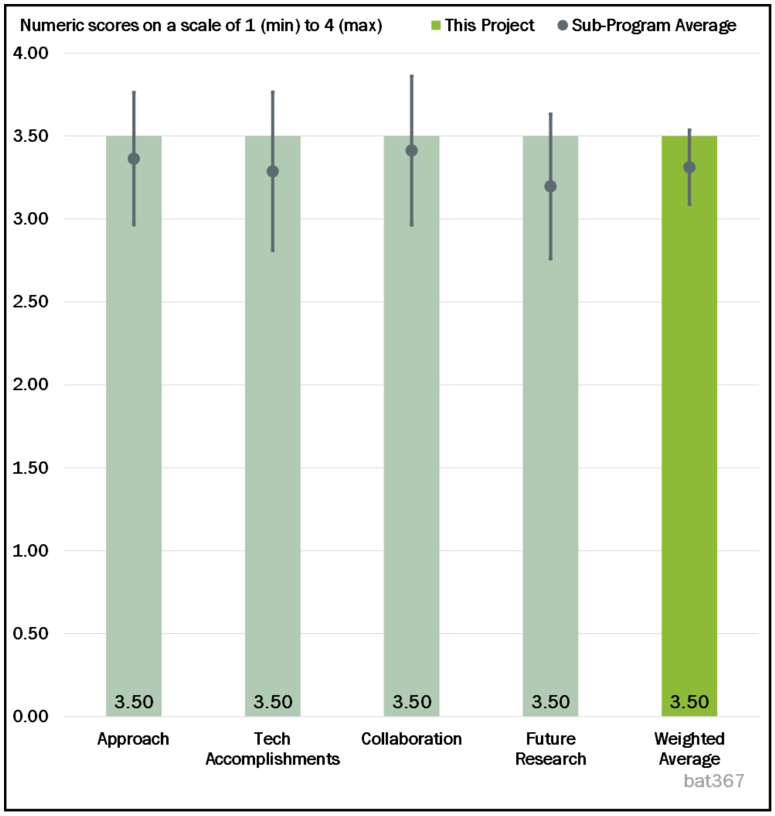

Figure 2-19 - Presentation Number: bat367 Presentation Title: Characterization Studies on Li-Metal Anode and High-Ni Cathode Materials Principal Investigator: Peter Khalifah (Brookhaven National Laboratory)

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 multi-scale and multi-dimensional techniques used and developed for the project (e.g., in situ and ex situ X-ray diffraction [XRD], pair-distribution function [PDF] TEM, and transmission X-ray microscopy are powerful tools to help achieve the Battery500 goals.

Reviewer 2:

The reviewer called this extremely high-quality work to characterize cathode materials, including heterogeneity.

The reviewer asked why the focus is on gravimetric energy density when volumetric energy density is more important for vehicles.

The reviewer saw no reference to working on Li-metal batteries although it is one of the main project objectives.

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:

These are outstanding technological and modeling developments. The reviewer wanted to know if the effect of large pores or regions of especially low porosity can be correlated with failure caused by local over-potentials.

Reviewer 2:
All are either completed or on schedule.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer found a broad array of highly qualified scientists with many areas of expertise on this project.

Reviewer 2:
It was unclear to the reviewer how the ex situ and in situ measurement results are being used by collaborators to improve the performance and durability of NMCs and sulfur electrodes. For example, how do collaborators use the "hot spots" (Slide 10) and cracking (Slide 12) observations to improve the electrode and the NMC particles?

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 directions are spelled out with some detail, not so common among the presentations that the reviewer has judged.

Reviewer 2:
The reviewer asserted that the single-particle-level measurements for mapping local strain and fracture should be carried out as a function of the cycle number, especially since a recent publication suggested that mechanical damages could occur in NMC particles during the first few cycles. See, for example, Dang, D., et al. (2019). "Fracture Behavior of Single LiNi0.33Mn0.33Co0.33O2 Particles Studied by Flat Punch Indentation." *JES* 166(13): A2749-A2751.

These measurements should also be carried out within each cycle since the strain distribution during lithiation is different from that during delithiation. The strain measurements should be compared with modeling predictions.

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

Reviewer 1:
Yes, the characterization tools are critical to help achieve the Battery500 objectives.

Reviewer 2:
The reviewer asserted that the project would be more relevant if the goal included a volumetric energy density. Do Li-S batteries provide good volumetric energy density?

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

Reviewer 1:
There are excellent in situ and ex situ characterization capabilities.

Reviewer 2:
The best facilities in the country are available to this project.

Presentation Number: bat368
Presentation Title: Battery500 Integrated Cell Diagnostics and Modeling to Identify Critical Gaps in Achieving High Cycle Life
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 indicated that the project was relevant to current DOE objectives, 0% of reviewers indicated that the project was not relevant, and 0% of reviewers did not indicate an answer. 67% of reviewers indicated that the resources were sufficient, 0% of reviewers indicated that the resources were insufficient, 33% of reviewers indicated that the resources were excessive, and 0% of reviewers did not indicate an answer.

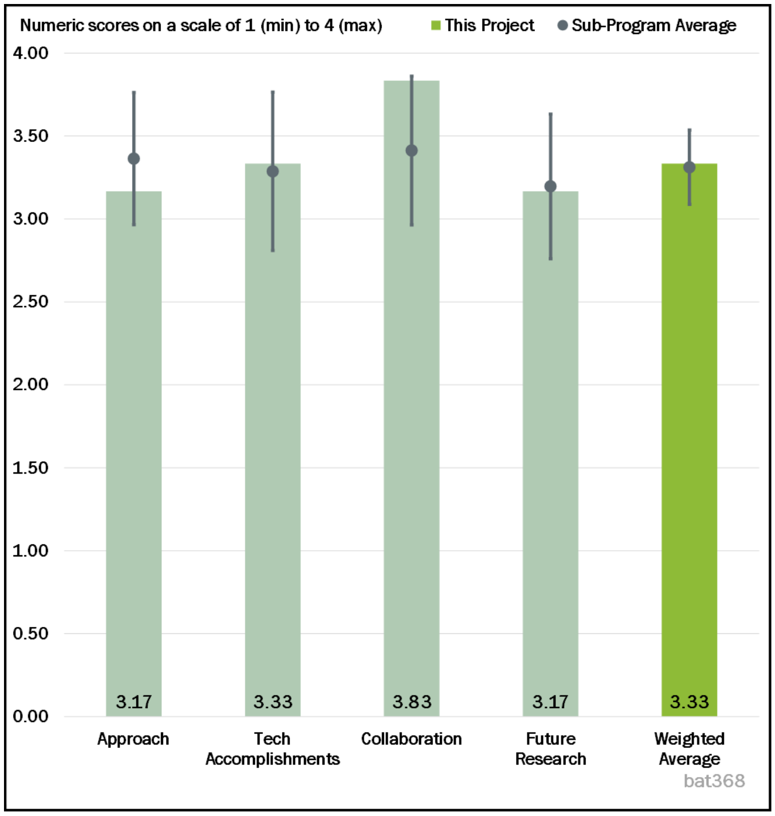

Figure 2-20 - Presentation Number: bat368 Presentation Title: Battery500 Integrated Cell Diagnostics and Modeling to Identify Critical Gaps in Achieving High Cycle Life Principal Investigator: Eric Dufek (Idaho National Laboratory)

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 stated that the technical barriers are suitably addressed with proactively developed solutions to mitigate the challenges.

The project is appropriately designed with sound scientific approaches and technical methods for completing the tasks.

Reviewer 2:

The INL team developed a failure diagnostic to separate thermodynamic from kinetic-capacity decay, which is critical for cell design and cell-performance enhancement.

The project is well designed. The electrochemical-analytic-diagnosis method was published in *JES* and applied to Li-metal batteries (LMBs).

Reviewer 3:

The reviewer asserted that there is no specific approach provided for the plan to understand the failure modes of Li-NMC and Li-S.

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:
Excellent progress has been made with significant results, including major findings and developments that could mitigate the technical barriers.

Reviewer 2:
The developed electrochemical analytic diagnosis has been applied to analyze the failure mechanism of LMB. Additionally, the spatial mapping of the cycled S electrode is important to understand the reaction kinetics of Li-S cells. Further, the reaction resistance can be obtained from electrochemical impedance spectroscopy (EIS) measurement and can be used to validate the kinetic resistance obtained from analytic diagnosis.

Reviewer 3:
This reviewer commented that cycling performance of cells cycled at two locations with different rates of capacity fade are shown without an explanation. Despite cells looking very similar during the first reference-performance test, they cycle very differently, without an explanation. The reviewer added that voltage relaxation shows how the impedance is only rising at the end of discharge and is limiting the intercalation of Li into the material, what the project team refers to as “cell kinetic imbalance,” without a real explanation of the source of the impedance.

Poor performance of Li-NMC cells is shown along with predictions of life where the number of cycles is under 50. Additionally, there is no explanation why the change in pressure with voltage is so much more dramatic for the first cycle than for later cycles when it appears to follow the capacity variation of the cathode with voltage. The reviewer also noted that the presence of S-O species in a cycled S electrode is shown without providing an explanation of where it might be coming from. Further, there is a claim that “kinetics and wetting” are interrelated and explain poor performance of poorly wetting sulfur structures.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The collaboration and communication across the Battery500 project teams are outstanding and will significantly enhance the success of the program, in the reviewer’s view.

Reviewer 2:
The INL team is closely collaborating with core Battery500 teams and seeding Battery500 teams and graduate research associates at North Carolina State University and Princeton University.

Reviewer 3:
The reviewer noted that the team made a point of showing where different National Laboratories made different contributions to the understanding of performance issues.

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 research clearly identifies the project risks and impacts to the proposed approaches to mitigate these risks.

Reviewer 2:
The future work will focus on electrochemical and mechanical interaction, which is critical for LMBs. The potential challenges are addressed.

Reviewer 3:
According to the reviewer, there is no specific plan laid out for future work as opposed to a long list of things the team still needs to get to.

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

Reviewer 1:
The reviewer noted that developing low-cost and high-energy-density batteries clearly meets the DOE objectives of reducing the cost of EV batteries while simultaneously improving the EV battery performance to make EVs affordable to all people.

Reviewer 2:
This project supports the overall DOE objective of developing 500 Wh/kg batteries.

Reviewer 3:
DOE's objective is to push the limit of battery energy density. The reviewer indicated that this project is looking at chemistries that can get to high energy density but either do not or do not cycle well.

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

Reviewer 1:
The project has sufficient resource to meet the milestone in timely fashion.

Reviewer 2:
INL has sufficient resources to achieve the stated milestones in time.

Reviewer 3:
This project, like all projects these days, lists the entire budget of the program so the reviewer was left to assume that all of the money must be going to this group. The team is making little progress for $10 million a year. In future years, the reviewer would appreciate an explanation that the team did not get the entire $10 million and let reviewers know which fraction of the $10 million was spent on this part of the effort.

Presentation Number: bat369
Presentation Title: High-Energy Rechargeable Lithium-Metal Cells: Fabrication and Integration
Principal Investigator: Jie Xiao (Pacific Northwest National Laboratory)

Presenter

Jie Xiao, Pacific Northwest National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers indicated that the project was relevant to current DOE objectives, 0% of reviewers indicated that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers indicated that the resources were sufficient, 0% of reviewers indicated that the resources were insufficient, 20% of reviewers indicated that the resources were excessive, and 0% of reviewers did not indicate an answer.

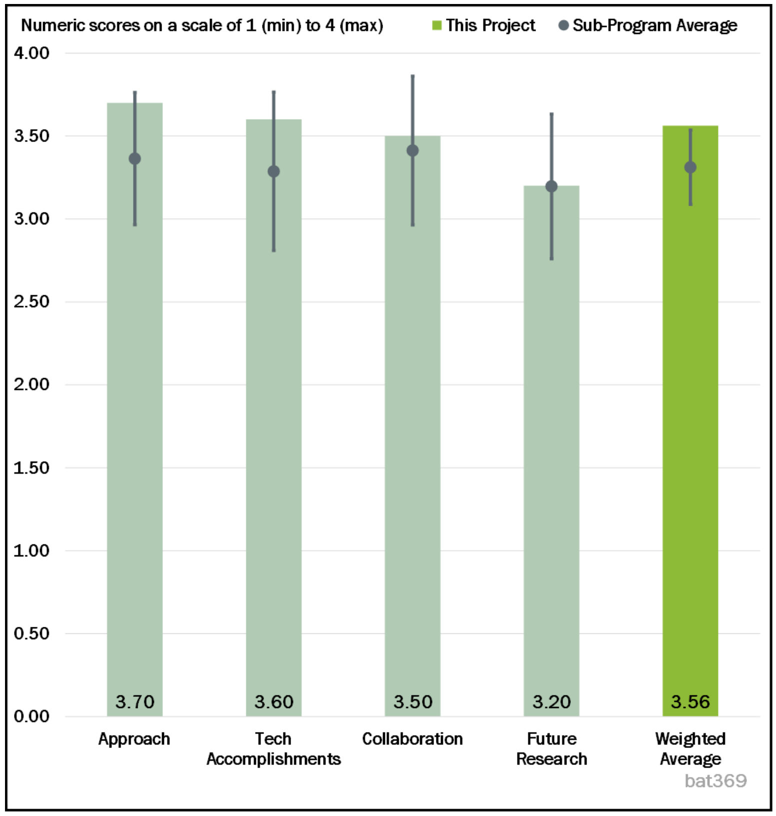

Figure 2-21 - Presentation Number: bat369 Presentation Title: High-Energy Rechargeable Lithium-Metal Cells: Fabrication and Integration Principal Investigator: Jie Xiao (Pacific Northwest National Laboratory)

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 technical barriers for developing high-energy Li cells are very well addressed. The dual approaches in developing Li -S and Li-NMC can potentially lead to the development of a low-cost Li-S cell that does not require the use of strategic metal in short supply, such as Co. The project objectives are well defined and the proposed technical approaches are feasible, according to the reviewer.

Reviewer 2:

The key factors limiting the performance of Li-S cells were identified. A safety protocol for studying high-energy Li- metal cells was developed.

Reviewer 3:

This project addresses the problem of capacity and energy stability with cycling. As such, the project's outcome is important for the overall success of Battery500. The team showed that electrolyte consumption is one component limiting life in a Li-S cell, most likely due to reactions of the electrolyte with Li. Adding more electrolyte increases life, the reviewer offered, probably by having enough electrolyte to react with Li metal to form a "stable" passivating layer and still have sufficient electrolyte for good cell performance.

Reviewer 4:

The focus is on the proper barriers, and the approach is leading to improved batteries. The reviewer asked why the team is focusing on gravimetric energy density when volumetric energy density is more important for vehicles.

Reviewer 5:
The reviewer indicated that the team has things it wants to accomplish, but an approach to achieving these milestones is not discussed on the Approach slide. As one goes through the technical accomplishments, there is mention of the final result of its work but not the approach or the details of how the accomplishment was achieved.

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 has made great progress toward a DOE Battery500 goal of high energy battery with 500 Wh/kg:

- Demonstrated Li-S cells with an energy density of approximately 313 Wh/kg but with limited cycle life that will needs to be optimized
- Developed Li-NMC cells with high energy density of 350Wh/kg and cycle life of 350
- Demonstrated 400Wh/Kg Li-NMC811 cell with limited cycle life of 50.

Reviewer 2:
The reviewer noted that 350 Wh/kg Li-NMC622 pouch cells achieved more than 350 stable cycles with 90% capacity retention. Additionally, 400 Wh/kg Li-NMC811 pouch cells achieved more than 50 cycles with 94% capacity retention. The correlation between cell-pressure change and electrode decay is critical to understand the capacity-decay mechanism.

Reviewer 3:
The reviewer posed a question about supposing the aim was 300 Wh/kg instead of 350. This is already much better than anything that is available commercially and would be highly valuable. How many cycles at what C levels could be achieved at 300? Industry would be very excited if the team can get that.

Great progress is demonstrated for NMC pouch cells although it was not clear to the reviewer exactly how this was done. Correlating pressure change with dead Li would be great, if it works.

Reviewer 4:
Progress in this project is very good. The team's progress has shown stable cell performance at 350 Wh/kg, with indications of similar stability at the 400 Wh/kg level.

Reviewer 5:
The team makes a claim that the cycling stability is a function of the amount of electrolyte by showing the results of adding more electrolyte. The reviewer's response was that there is no theory put forth as to why more electrolyte results in better cycle life but not higher capacity per gram of S. The team claims that the polysulfides react with the electrolyte, but does not describe the reactions as chemical, reductive, or oxidative. The project team provides little evidence for this claim. If the electrolyte reacted with the polysulfides, the reviewer questioned whether the capacity of the cell would decrease with time as these reactions proceeded. Because the polysulfides are solubilized, there would be no reason for the reactions to stop unless they reached an equilibrium state and an increase in electrolyte would result in more polysulfides being consumed.

Because more electrolyte helps with cycling, the team wants to make more room for electrolyte by reducing the binder content. The reviewer observed that the team also wants to reduce the porosity, which seems to go against a higher electrolyte concentration. It would be nice to hear the hypothesis on why more electrolyte helps.

The team shows cycling data of NMC 622 and NMC811 and that 350 Wh/kg and 400 Wh/kg can be achieved. There is no explanation about the challenges that had to be overcome to get to this point and what the team did.

The team shows a graph of yearly progress in cyclability, with very few details other than through the modifications of the electrode, the electrolyte, and cell design. What is the reviewer to take from that?

The team developed a test fixture to measure the pressure of the cell with cycling. The final pressure gradually increases with charge and is constant on discharge. The team hypothesized that this is caused by the formation of dead Li. If the Li is dead, the reviewer questioned if it had been present on charge and discharge. In the end, the reviewer noted the progress in cell fabrication, but stated that very little detail on how was provided.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
With regular interchange in ideas and frequent meetings, the collaboration and coordination across project teams are excellent.

Reviewer 2:
Jie Xiao's team has closely collaborated with three companies, nine universities, and three National Laboratories.

Reviewer 3:
There was ample evidence that the collaborators are working as a cohesive team. The contributions from each member were clearly spelled out.

Reviewer 4:
The reviewer found a ton of coordination.

Reviewer 5:
There was good collaboration across the laboratories.

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 work is well thought out and focused on the overall project goal.

Reviewer 2:
Jie Xiao's team identified the challenges and proposed plans to address these challenges.

Reviewer 3:
According to the reviewer, the presentation listed "Further improve cycling" and "Stabilize interfacial reaction" as proposed future work. The reviewer wanted to know what approaches will be taken to accomplish these tasks.

Reviewer 4:
The reviewer indicated that future work for improving the cycle life of 313 Wh/Kg for Li-S cells and 400 Wh/Kg for Li-NMC811 cells is well presented and effectively planned. It will be challenging to reach the goal of 500 Wh/kg for Li-NMC811 cells with long cycle life by the end of this project in 2020.

Reviewer 5:
The project team plans to increase the energy density by introducing new concepts, considering the balance between cycle life and thicker Li, and trying to limit cell shorting by charging at C/10. There is no plan given here.

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

Reviewer 1:
The reviewer indicated that this project addresses the problem of capacity and energy stability with cycling. As such the project's outcome is important for the overall success of Battery500. The team's progress has shown stable cell performance at 350 Wh/kg, with indications of similar stability at the 400 Wh/kg level. These are important stepping stones for DOE's goal of 500 Wh/kg.

Reviewer 2:
This project will advance the development of high-energy rechargeable and low-cost Li-metal batteries for DOE EV applications.

Reviewer 3:
Ji Xiao's work directly addresses the DOE Energy Efficiency and Renewable Energy (EERE) Battery500 core objective.

Reviewer 4:
The reviewer found the project to be very relevant to DOE objectives.

Reviewer 5:
The project supports DOE's effort to increase the energy density of cells. However, the reviewer asserted that the team is not very forthcoming about what it is doing. It was if this were a presentation from a company that was protecting every bit of data because of intellectual property (IP). Is this a project meant to generate IP or provide guidance to other researchers toward making higher energy density systems?

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 PNNL has the best equipment and resources for proposed milestones.

Reviewer 2:
The resources allocated to the project seem reasonable.

Reviewer 3:
Resources are sufficient.

Reviewer 4:
The team has sufficient resources to meet the Battery500 program goal.

Reviewer 5:
The PI for this project provided the total funding number. The reviewer can only assume that all $10 million was spent on the work presented. It should not be that hard to figure out how many folks actually contributed to creating the graphs of the data presented for this particular project or there may be a bigger problem in tracking the spending.

Presentation Number: bat370
Presentation Title: Advanced Diagnostics of Nickel-Rich, Layered-Oxide Secondary Particles
Principal Investigator: Mike Toney (Stanford University/SLAC)

Presenter

Mike Toney, Stanford University/SLAC

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

100% of reviewers indicated that the project was relevant to current DOE objectives, 0% of reviewers indicated that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers indicated that the resources were sufficient, 0% of reviewers indicated that the resources were insufficient, 20% of reviewers indicated that the resources were excessive, and 0% of reviewers did not indicate an answer.

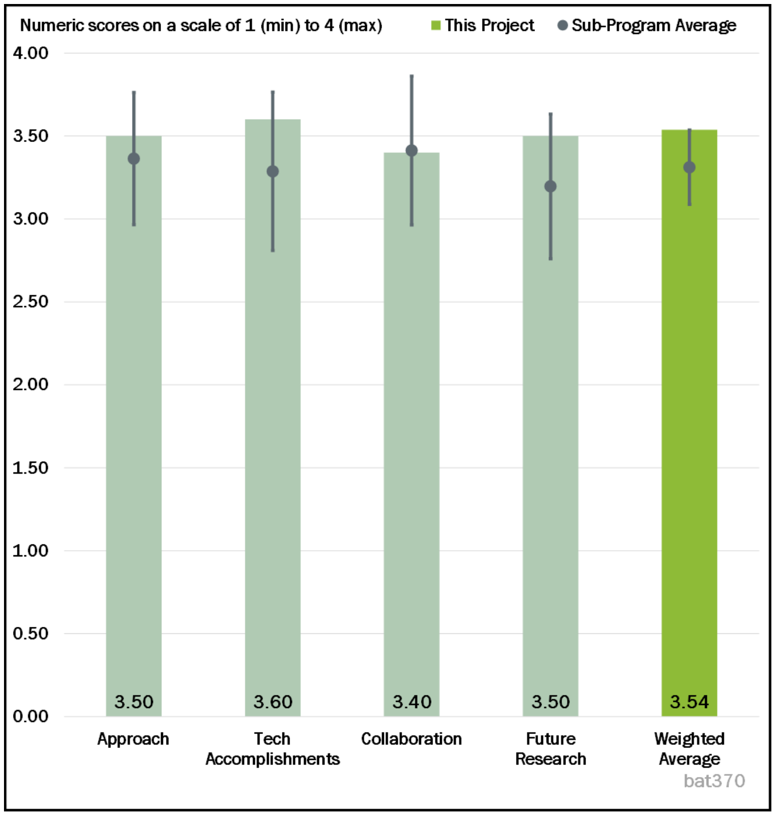

Figure 2-22 - Presentation Number: bat370 Presentation Title: Advanced Diagnostics of Nickel-Rich, Layered-Oxide Secondary Particles Principal Investigator: Mike Toney (Stanford University/SLAC)

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 team uses in situ and ex situ synchrotron X-ray based spectroscopy and microcopy techniques to investigate the behavior of Li-rich cathode materials at different length scales. Using the structural, chemical, and mechanical information obtained from these studies, the project aims to provide understanding of materials-failure mechanisms. The reviewer asserted that this is an excellent approach that is well thought out and effective in addressing the barriers in cathode-materials development.

Reviewer 2:

In situ and ex situ X-ray probes were utilized to investigate the structure stability of Li-Mn-rich cathode materials. Concentrated effort was devoted to understanding the mechanism of O redox and the voltage fade during charging and discharging. The adoption of an element-sensitive technique to differentiate Mn, Co, and Ni will be a huge plus for this project.

Reviewer 3:

The projects bring together numerous approaches that can be used to evaluate O loss in Li-Mn-rich (LMR)-NMC and to understand the issues with this material. Both averaging tools and particle-level diagnostics were presented. The reviewer found the work to be very impressive.

Reviewer 4:

The objective of understanding the origin of activation and degradation of LMR-NMC is achieved.

Reviewer 5:
LMR-NMC materials have been well studied, especially using X-ray studies. The reviewer indicated that it is difficult to propose new studies that have not been done. Still, the quality of these measurements continues to improve.

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 found the results to be impressive. The presentation showed how O loss occurs using a combination of tools. It was very comprehensive and detailed.

Reviewer 2:
The quality of these studies is excellent. The reviewer remarked that it is unfortunate that there is no synthesis collaboration that would allow more flexibility. The rich chemistry and microstructure of these LMR-NMC materials can have a huge impact on performance. It was hard for the reviewer to separate conclusions that are supported by previous work from the ones that are unique to this study.

Reviewer 3:
The team has made significant progress in terms of understanding O-redox active materials. The techniques used were appropriate, and the coupling of TM migration and O redox as well as the mechanism behind it were clearly explained.

Can the team illustrate the connections among O redox, TM migration, O vacancy, and O diffusion processes? Also, what triggers O redox and TM migration and which one comes first? The reviewer would like to see a more rounded picture of these processes and how they affect the performance of the cathode materials but understood that the project has now ended.

Reviewer 4:
The correlation between the TM migration with the O redox was observed. In addition, the periodic transition migration between the TM layer and Li layer was reported during the charging and discharging process. Phenomena- wise, this project successfully associates the slow kinetics of voltage fade to periodic migration of TM. As generally seen in this structure community, the potential impact of carbonated-based electrolyte at such high potential was not discussed at all.

Reviewer 5:
Technical accomplishments are clearly demonstrated in the presentation and summarized concisely on Slide 16.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The team made a good use of National Laboratory user facilities. According to the reviewer, the work was well coordinated.

Reviewer 2:
This team has a strong collaboration with other research teams and Battery Materials Research Program (BMR) projects.

Reviewer 3:
Excellent collaboration, though it was unclear to the reviewer what role the “industry” partner had other than providing the materials. Did the knowledge gained from the project help the industry?

Reviewer 4:
Some collaborations are listed. The work appears to be relatively independent.

Reviewer 5:
There are collaborations with the Advanced Light Source (ALS), but the reviewer did not see much more. Maybe that is okay, but the reviewer would like to have seen theoretical predictions complementing the experiments. There were theorists in the list of collaborations, but no results were 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:
This project has ended.

Reviewer 2:
This is an end-of-project review. No future work was presented.

Reviewer 3:
The project has ended.

Reviewer 4:
There is no proposed future work, but the project has finished.

Reviewer 5:
It appeared to the reviewer that the future work seems logical.

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

Reviewer 1:
Excellent fundamental studies were carried out in this project to improve existing cathode materials. This is highly relevant to DOE's objectives in developing high-energy LIBs.

Reviewer 2:
In the past two decades, DOE has heavily invested in the material development of LMR cathode materials. This class of materials has a higher energy density than other counterparts. Further understanding the voltage-fade mechanism can shed light on the potential mitigation of such barriers and enable them for high-voltage and high- energy-density applications.

Reviewer 3:
The reviewer stated that fundamental knowledge gained through this project will be useful to help achieve the DOE objectives.

Reviewer 4:
If the results of this study would lead to a better LMR-NMC, then that would reduce the cost of batteries.

Reviewer 5:
The reviewer indicated that understanding voltage fade and oxygen loss is critical.

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

Reviewer 1:
Resources were used to develop and utilize a correlative microscopy platform that included in situ and ex situ X-ray spectroscopy, diffraction, and microscopy to correlate local chemistry, structure, and microstructure evolution to battery performance and durability relevant to fast charging,

Reviewer 2:
The resources are sufficient, and the project was completed.

Reviewer 3:
The resources seemed sufficient to the reviewer to conduct the studies.

Reviewer 4:
There was good use of resources.

Reviewer 5:
The reviewer said that resources are sufficient.

Presentation Number: bat376
Presentation Title: Disordered Rocksalt Transition-Metal Oxides (TMOs): Recent Advances
Principal Investigator: Gerbrand Ceder (Lawrence Berkeley National Laboratory)

Presenter

Gerbrand Ceder, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

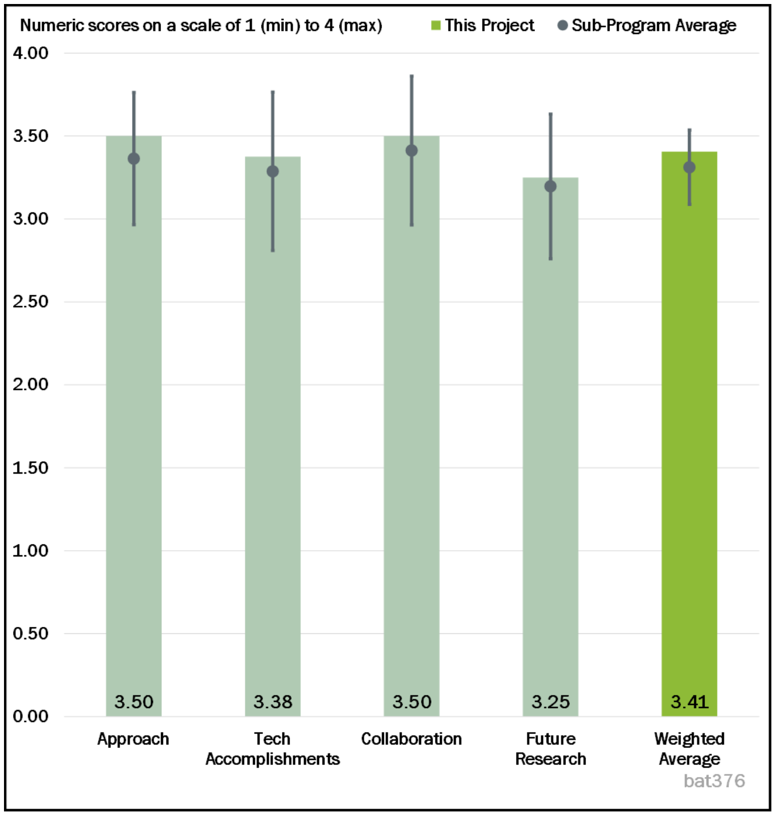

Figure 2-23 - Presentation Number: bat376 Presentation Title: Disordered Rocksalt Transition-Metal Oxides (TMOs): Recent Advances Principal Investigator: Gerbrand Ceder (Lawrence Berkeley National Laboratory)

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 first presentation gave an overview of the cation-disordered rock salt (DRX) project and clearly described the motivation, barriers, and strategies with multiple teams. It indeed helped the reviewer to understand the big picture of the overall DRX project. The second presentation focused on surface studies and high-voltage potential, especially on Li-Mn-Nb-O-F (LMNOF). The project has addressed the technical barriers adequately and demonstrated the effectiveness of problem-solving efforts.

Reviewer 2:

The approach focused on three DRX baseline powders (none of them with Co content) coupled with a variety of spectroscopic techniques, and the modeling studies are impressive. The project is good and feasible.

Reviewer 3:

DRX is a promising new class of Co-free Li-ion battery cathodes.

Reviewer 4:

DRX materials provide attractive alternatives to NMC-type cathodes. The reviewer remarked that it is good that whole team is working on the selected three materials. Co replacement by Nb or Ti may be even more problematic in terms of the material sustainability. Another concern is the high content of reactive F, which may be significantly problematic when batteries catch fire and result in the release of hydrofluoric acid (HF).

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 overall DRX project has reached several impressive findings and accomplishments. The second presentation first expressed the key observation on the Li-Mn-Ti-O-F (LMTOF) and LMNOF. The team utilized several techniques and approaches to investigate the cathode itself and evolution with electrolyte upon cycling for LMNOF. In the study focused on surface analysis, the reviewer observed that it would be interesting to correlate with bulk imaging for structural analysis to understand the dissolution and structure change.

Reviewer 2:

According to the reviewer, the amount of technical information the team managed to collect on these novel DRX compounds was impressive. The modeling and calculations the team presented, such as the one used as guidance for the F-substitution experiments, were impressive. It could be of great interest if the team can put together a simple model to explain the reason behind the lower surface energy found for the 001 and 110 facets, for example.

Reviewer 3:

The F solubility issue has been examined. The voltage-fade issue is a link to electrolytes. The reviewer noted that the short-range order was studied in depth using a variety of complementary techniques.

The composition is widely varied and studied; it would be useful to develop some unifying quantitative mechanism that can explain the data.

There is an interesting transition observed between spinel and rock salt structures and the resulting stabilization effect. The reviewer said that the in-depth surface study was well done.

Reviewer 4:

There were good insights on surface characteristics of LMTOF materials as well as interesting insights on the mitigation of voltage and capacity fade via pre-treatment.

The overall performance still seemed underwhelming to the reviewer; perhaps more time is needed to fully understand this interesting new material and its practical usefulness.

Extending the disorder concept to spinels is innovative.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The teams strongly collaborate with each other; in particular, the reviewer remarked that it is nice to see the theoretical group strongly interacting with the experimentalists and complementing each other.

Reviewer 2:

It is an excellent team and collaboration.

Reviewer 3:

In the presentation, the reviewer clearly saw the overall DRX project, which indicated how the teams contributed their efforts to the novel DRX materials. To develop and understand the novel materials, the challenges are inevitable. It requires good collaboration and coordination between teams. As the work includes a great collaborative effort from several areas of experts, the reviewer suggested that efficient communications and learnings across teams could speed up the development process.

Reviewer 4:
The reviewer found collaboration to be good.

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 plan is generally well thought out and demonstrates the clear knowledge of the key challenges from synthesis improvement, material design, and investigating the origin of electrochemical properties. As the project focus is toward F optimization and understanding, the reviewer said that it could be helpful to design the strategic approach to study and compare regular DRX and fluorinated DRX materials.

Reviewer 2:
The evaluation of the F-solubility limit seems very important as it may hint at potential improvements for these DRX powders. The reviewer found it very interesting to see that the source of F released from these DRX powders is coming from lithium hexafluorophosphate ($LiPF_6$) present in the electrolyte. The studies focused on the surface versus bulk effects of the electrochemical performance degradation for these powders, which seem very important, and the team is already fully involved in that area. The synthesis of these DRX materials could become very important in the future, in particular when trying to scale up the production process for these DRX compounds.

Reviewer 3:
This is an extension of the current work.

Reviewer 4:
The future work is adequate; perhaps it can be more ambitious in terms of actual performance improvements.

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

Reviewer 1:
The novel DRX materials provide the potential for the alternate cathode material. It is well aligned with DOE-VTO objectives.

Reviewer 2:
This project is very relevant for the DOE objectives. As the team members have shown, the three DRX powders presented in this study, for example, are absolutely Co free.

Reviewer 3:
This project is relevant to DOE objectives.

Reviewer 4:
Work is relevant to the program, but it was not clear to the reviewer if the proposed cathode material is environmentally sustainable.

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

Reviewer 1:
The DRX project gathers sufficient resources from several talented teams and National Laboratories. The reviewer stated that the team has adequate credentials, experience, and resources to execute the project.

Reviewer 2:
The team has a good access to the needed resources.

Reviewer 3:
Resources are sufficient.

Reviewer 4:
The project may need additional support if DOE decides to scale up the production process for these new types of materials.

Presentation Number: bat388
Presentation Title: Silicon Deep Dive: Update and Overview
Principal Investigator: Jack Vaughey (Argonne National Laboratory)

Presenter

Jack Vaughey, Argonne National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

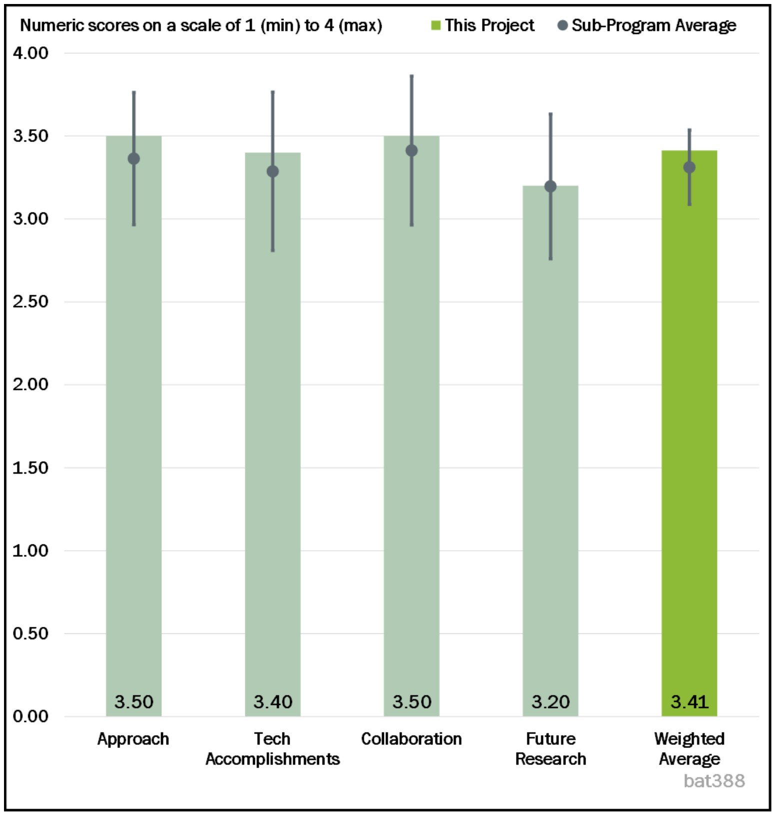

Figure 2-24 - Presentation Number: bat388 Presentation Title: Silicon Deep Dive: Update and Overview Principal Investigator: Jack Vaughey (Argonne National Laboratory)

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 work on cell design and electrodes is really critical and under-represented in the industry. The reviewer was very glad to see this work included in the project. The work on FEC is also practically important since it is so heavily used with Si. The reviewer thought that this presentation was the most relevant to commercial systems.

Reviewer 2:

The project is well organized, well designed, and highly focused. It was very evident to the reviewer that a lot of careful thoughts went into planning this project.

Reviewer 3:

The Silicon Deep Dive is focused on addressing calendar life and cycle-life issues with Si-anode technology. The team is taking a practical approach via materials stability, cell and electrode design, and failure analysis. Various responsible parties on the sub-thrusts are easily identified and project areas are delineated. Project categories are appropriate for solving Si issues.

Reviewer 4:

The overview to the Silicon Deep dive program did a good job of addressing the important technical barriers and does a good job coordinating the large number of researchers working on the project. The goals of the project are clear, and the design of the work groups and work packages are good. The project has feasible goals that will likely provide benefit to the U.S. automotive industry by laying the groundwork to improve the energy density of anodes for LIBs.

Reviewer 5:
It was not clear to the reviewer what new approaches are being taken to make Si viable: C coatings have been tried over many years. Please explain how these experiments can lead to improved 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:
This project has addressed four critical topics related to the development of Si anodes for LIBs. First, what is the quality and surface chemistry of the Si materials along with the design of the cells? These are important issues, and the team has addressed the problems in a systematic and effective manner.

The second area is slurries and laminate design. This issue is a very important challenge for Si electrodes and is often overlooked in research settings. The team has approached the problems in a very systematic manner and has developed novel methods to investigate changes to both slurry design and laminate structure and the effect on performance.

The third area is surface functionalization. It was clear to the reviewer that one of the primary problems associated with Si-anode materials is the surface chemistry of the Si particles. The team has designed some interesting and novel methods to modify the surface of the Si particles to improve the performance.

The surface functionalization is related to the fourth area, which is SEI formation and stability. The SEI on Si anodes is very complicated and important for the overall function of Si anodes. The team has utilized novel methods to investigate the thermal stability of the SEI with different electrolytes. This study has provided important fundamental information, which will greatly benefit the development of Si anodes.

Reviewer 2:
This project has a lot of practical progress. The reviewer appreciated that the team addressed a reviewer comment from last year that the project was too exploratory. The reviewer thought that there is a much better balance now, and technical accomplishments are very relevant.

Reviewer 3:
The project has made significant contribution toward fundamental understanding of Si-anode properties using a variety of state-of-the-art analytical techniques. This has been the salient feature of these investigations, and the reviewer gave kudos to the teams for doing an excellent job in achieving this objective.

The reviewer was kind of hoping that this high-powered talented team with significant resources and time will be coming up with a solution for the Si anode that will be ready for use in a long-life cell. However, based on the current data, it was not clear to the reviewer that the teams were able to achieve that goal.

Reviewer 4:
The presenter described significant technical accomplishments that occurred over the previous year. For example, the development of the porous Si material with C coatings appeared to the reviewer to be a significant development and should be investigated further as it seems to be a practical approach to improving Si performance. Additionally, the discussion of full-cell design and related electrode expansion was refreshing to the reviewer and demonstrated an understanding of some industrially relevant metrics for commercialization. Technical Accomplishments are practical and may be applied more broadly to other systems as well.

Combining some of the most promising approaches together to confirm that they are additive rather than "mutually exclusive" would be re-assuring regarding the validity of the approach (i.e., porous Si-C material, with improved negative-positive (N/P) ratio studies, and Mg-salt addition). Parenthetically, the reviewer also asked does each part lead to incrementally better performance and would the SEI still show dissolution with the Mg salt and porous Si-C material?

Reviewer 5:
The reviewer provided the following comments:

- The Si results look good, but no CE numbers are provided.
- Si-tin (Sn) results are available for only 20 cycles.
- Slide 9 shows "Less Si is cycled as the negative cycling window changes; this would decrease the electrode volume expansion and reduce the rate of capacity fade as the aging progresses." This is well known; limiting Si utilization is a standard approach for Si in electrodes.
- The reviewer did not see an overarching, overall strategy that will lead to a Si-based anode or full cell.
- Increasing the N/P ratio adds weight. Why not just limit voltage range, which is normally done, to increase lifetime?
- Binder interactions are a very important area to study.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This is an overview of a large team project. The team clearly interacts regularly and utilizes the resources of different National Laboratories effectively. The projects leaders do a good job of coordination of the many different projects. Since the performance of Si anodes is dependent upon many different factors, a large team approach with many different researchers studying the same materials is very important for the development of a consistent understanding of these complicated materials.

Reviewer 2:
The reviewer noted that this is a well-coordinated team project that really leveraged the excellence of each National Laboratory.

Reviewer 3:
Specific collaborations are called out. The reviewer wanted to know how this collaboration connects to that of Burrell.

Reviewer 4:
The presenter highlighted collaboration and coordination between project teams and mentioned at the outset how the individual pieces fit together. The reviewer found this to be very well organized and well-presented regarding collaboration and coordination.

Reviewer 5:
There seems to be good collaboration across a very large team. The reviewer would like to have seen more cross- team conclusions drawn from pooled results.

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 appropriate remaining challenges and barriers as well as future work to address those issues. Some future work was concrete (i.e., better slurry processing routes, identifying the role of additives in aging and slurry stability, and Si-specific Battery Performance and Cost models), and directions were well thought through. Efforts to improve reproducibility and evaluation were also described (develop new scale-up processes), which are very high priority to ensure that results can be generally applied and are not limited to small-scale individual investigations.

Reviewer 2:
The proposed future research areas are the most important topics for further development of Si anodes. The effect of SEI structure, stability, and dissolution will lead to the development of superior surface films and improved performance. Continued evaluation of the slurries will also lead to important practical advances. Finally, the development of consistent materials for investigations will greatly assist uniformity of the investigation across the entire team.

Reviewer 3:
The reviewer's reservation was whether the proposed work will lead to a commercially viable solution and be competitive with state-of-the-art Si technologies.

Reviewer 4:
Future work focuses on functionalization/modification of the Si surface. The reviewer asked about the certainty of knowing what functionalities will ultimately succeed as the reviewer thought that it might be a little too early to talk about scale up.

Reviewer 5:
After decades of work on graphite SEI composition and structure, the reviewer was not aware of how these studies have led to any battery improvements. Instead, improvements have come from empirical approaches to add various additives. These additives were mostly discovered without the benefit of understanding how they work. Therefore, and by analogy, the reviewer was not convinced that an improved understanding of Si SEI will be a useful path forward.

There is no discussion of calendar life.

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

Reviewer 1:
This project is very relevant since it is focused more on the applied research portion of the Si-anode development. The reviewer commented that Si anodes are a key technology to decreasing battery costs, increasing EV adoption, improving our energy independence, and becoming a world leader in battery technology.

Reviewer 2:
This project supports the DOE objectives of developing lower cost, higher energy density LIBs for electric vehicles. The development of improved Si or Si-C composite anodes is one of the few viable methods to increase the energy density of the anode for LIBs. This team is addressing the important problems in an appropriate manner.

Reviewer 3:
The reviewer noted that Si anodes are required to achieve the DOE energy-density roadmap for automotive application. This project seeks to understand and address the challenges of implementing Si in automotive cells with long cycle life and calendar life.

Reviewer 4:
This project is highly relevant to DOE's overall objective.

Reviewer 5:
Is $125/kWh good enough to be worthwhile studying?

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

Reviewer 1:
Resources seemed appropriate to the reviewer and sufficient to achieve the program milestones and have coordination and collaboration between the partners.

Reviewer 2:
The reviewer believed the resources and the time provided to this project were sufficient and significant.

Reviewer 3:
Resources are sufficient.

Reviewer 4:
The resources are sufficient.

Reviewer 5:
The reviewer thought that resources are sufficient—it is a very large team.

Presentation Number: bat392
Presentation Title: Enabling Rapid Charging in Lithium-Ion Batteries via Integrated Acoustofluidics
Principal Investigator: James Friend (University of California at San Diego)

Presenter

James Friend, University of California at San Diego

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

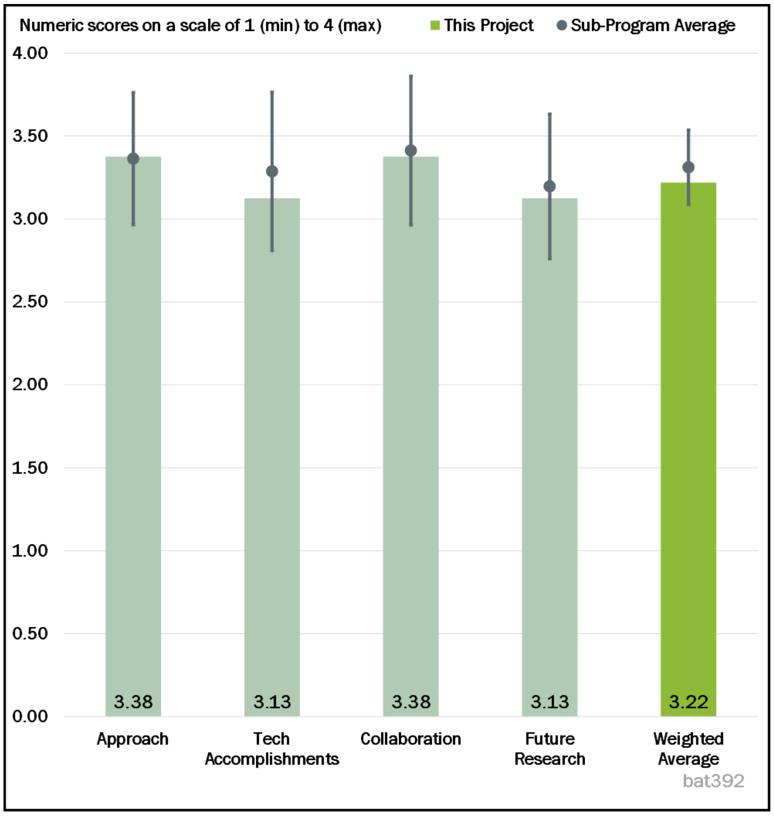

Figure 2-25 - Presentation Number: bat392 Presentation Title: Enabling Rapid Charging in Lithium-Ion Batteries via Integrated Acoustofluidics Principal Investigator: James Friend (University of California at San Diego)

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 research showed clear improvement in capacity attained during fast charge. According to the reviewer, it will be more feasible if the device can be utilized external to the cell as proposed for future work. It may also be of interest to look at electrolyte systems that have favorable attributes, such as non-flammability or high-voltage tolerance yet are too viscous for application. This might be another application of this technology. Making the device smaller will make it more feasible.

Reviewer 2:

The approach, to start with, was to improve the fast-charging capability of the baseline Li-ion cells by choosing appropriate electrode materials and electrolyte components and understanding the effects of temperature. In parallel, the project has focused on the design and optimization of the surface acoustic wave (SAW) device tailored to the battery, the material characterization in the cells cycled with the integrated SAW, and the development of a model for the acoustically driven fluid flow. The approach here is feasible conceptually to enhance Li-ion mobility for preventing dendritic Li deposition at high charge rates.

One serious limitation of this technology is its invasive nature: i.e., the device is in intimate contact with the electrolyte. Even though it appears there is little effect on the cell performance with the integrated SAW within the cell, its long-term effects will be questionable. The reviewer commented that it would have been better if such a device can be instrumented outside the cell, which will eliminate this problem and also allow the commercial cells to be used with the device.

The task is well oriented to improve fast-charge capability of Li-ion cells, as required for EV batteries. The project is well integrated with other VTO projects.

Reviewer 3:
The technology offers the potential of improving the fast-charging capabilities of a single cell or a full system. It was not clear to the reviewer, however, how it can be easily implemented into or onto a cell and/or module for a vehicle application. Would the system need to be placed on every cell in a battery pack? If it were placed on a module or pack, is there a need for the sonic wave to be consistent across each cell? If so, how would that consistency be maintained across each cell and not introduce any life issues?

Reviewer 4:
The technical approach addresses the battery fast charging by using SAW on cells developed in-house.

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 SAW LIB showed an almost two-fold improvement in energy density under fast-charge (15 min.) conditions, indicating good progress. The lifetime of the cell is improved. The reviewer suggested that some thought should be given to application in a multi-cell battery.

Reviewer 2:
Overall, the progress achieved here is meaningful and relevant to DOE goals. Reasonably good progress has been made in demonstrating the efficacy of the SAW device in promoting Li-ion diffusivity and thus the performance during cycling at high charge rates. The SAW device has been successfully miniaturized for incorporation into the cells. Also, characterization of the cycled batteries indicate that the electrode degradation is reduced with SAW. The results are interesting and encouraging. However, the reviewer had a few questions and a comment, as listed below:

- Why is the specific energy so low for the baseline cell (100 Wh/kg)? The challenge is to have high charge capability in a high energy cell with dense electrodes. Are the specific energies mentioned here normalized to low rate charges and discharge (e.g., C5-C/10)?
- Was the SAW device integrated in a jellyroll cell (20700)? Data for the pouch cell are only shown here.
- What causes the cathode to degrade in regions away from the SAW device?
- There is no change in the anode from neutron diffraction. Does it mean the differences caused by the SAW device are only on the surface of the anode, not the bulk? Does it imply that the SAW does not prevent Li plating but only prevents dendrites?
- Even though the cycle life is good with the SAW integrated within the cell, the total duration for this test is less than a month. The long-term effects of the SAW being in contact with electrolyte are therefore still unknown.
- How is the SAW sized for a given cell in relation to the size of the cell, amount of electrolyte, etc.?

Reviewer 3:
The technical approach is sound, and the progress is aligned with the plan.

Reviewer 4:
The project demonstrates that the technology improves the fast-charge capabilities of a single cell. Ideally, the project needs to confirm the overall effectiveness of the technology in a high-voltage vehicle battery with a cell format 35 Ah or greater. Also, the application would need to be at either the module or pack level rather than at the cell level.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

There are good, on-going collaborations with the University of California at San Diego's Qualcomm Institute for the design and testing of SAW circuit, with ORNL for neutron characterization on cycled Ah pouch cells, and LiFung for the fabrication of large format pouch LIB cells. It was not clear to the reviewer where the cylindrical (jelly) roll cells 20700 were made, however.

Reviewer 2:

The reviewer noted that the collaborations seem to work okay in the context of this project. The partners worked on the areas of their expertise. The feedback loop between the collaborators was not that evident to the reviewer, but the positive results suggest that it worked at some level.

Reviewer 3:

The project appeared to the reviewer to be involving the right teams to make the technology work. More involvement with a final end user (i.e., vehicle original equipment manufacturer [OEM]) would help.

Reviewer 4:

The contractor has put together a strong team with extensive experience in attacking battery fast-charging technical barriers.

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 significant challenges still remain in implementing this technique in LIBs to improve to fast-charge capability. These are related to placing the μ-particle image velocimetry on a transparent battery to improve the mathematical model used for design; placing the SAW in a large LIB; and placing the SAW outside the cell so that it may be retrofitted in commercial LIBs. Finally, being chemistry-agnostic, the SAW-driven, acoustic-streaming approach may be extended to Li-metal batteries, including Li-S, to prevent dendritic Li deposition during charging. Future studies in this project are planned effectively and logically.

Reviewer 2:

The reviewer indicated that the project needs to clearly show how the technology cost will be controlled and how the processing and manufacturing will be done to incorporate the technology in order to maximize its effectiveness. These two concerns seem to be part of any future development work.

Reviewer 3:

Demonstration across platforms would be of interest. Thick loadings might also be of interest. Using this tool to enable electrolytes that might be too viscous under normal operating conditions might be of interest. Application in a multi-cell pack needs to be thought out and done.

Reviewer 4:

The presentation did not include the impact of acoustic waves on electrode over-potential. The reviewer suggested that the project add electrochemical study on the impact of acoustic waves on cell overvoltage if it has not been done. In addition, the reviewer suggested adding a study on comparing coulombic efficiencies with and without acoustic waves during fast charging.

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

Reviewer 1:
The overall objective is to increase the energy density of Li-ion cells to more than 180 Wh/kg during fast charge (6C), and the premise is that improved Li-ion diffusion in the electrolyte from acoustic streaming will allow rapid charging without the formation of dendrites. Specifically, this project has developed a scheme to integrate the SAW device in a Li-ion cell to enhance Li mobility between the electrodes and mitigate the interfacial degradation at the anode during fast charge. Additionally, a mathematical model is being developed for Li diffusion in the presence of acoustically driven flow and to correlate the predictions with the experimental data.

According to the reviewer, the project duly addresses the barrier of low specific energy of Li-ion cells during cycling involving fast charge. The project is well designed and well planned to enhance rapid-recharge capability of LIBs, which is one of the requirements for EVs and is thus consistent with the goals of DOE-VTO program.

Reviewer 2:
The reviewer found a clear need to improve the fast-charge capabilities of current, high-voltage electrified vehicle systems to make them more acceptable. The development and implementation of this technology offers a chemistry-agnostic solution that will help move the needle in that acceptance direction.

Reviewer 3:
The reviewer stated that it is relevant to lowering the tradeoff in energy density and lifetime that occurs in state-of-the-art (SOA) cells under fast-charge conditions. Fast charging may increase driver acceptance of EVs.

Reviewer 4:
The project supports the goals for battery charging-time reduction.

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

Reviewer 1:
The funding seemed sufficient to the reviewer, considering that commercial off-the-shelf (COTS) battery materials are used for cell construction and the device is also build from COTS components.

Reviewer 2:
The resources are appropriate for the scope of the project.

Reviewer 3:
The resources appeared to be sufficient to the reviewer for the proposed efforts. But it may save time for the team to have a partner (such as a National Laboratory) in building cells with specific energy density meeting the requirement for the experiment.

Reviewer 4:
The resources are sufficient to develop and demonstrate the technology. Involvement of end users should be viewed as the next step.

Presentation Number: bat393
Presentation Title: Development of an Extreme Fast-Charging Battery
Principal Investigator: Chao Wang-Yang (Penn State University)

Presenter

Chao-Yang Wang, Penn State University

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

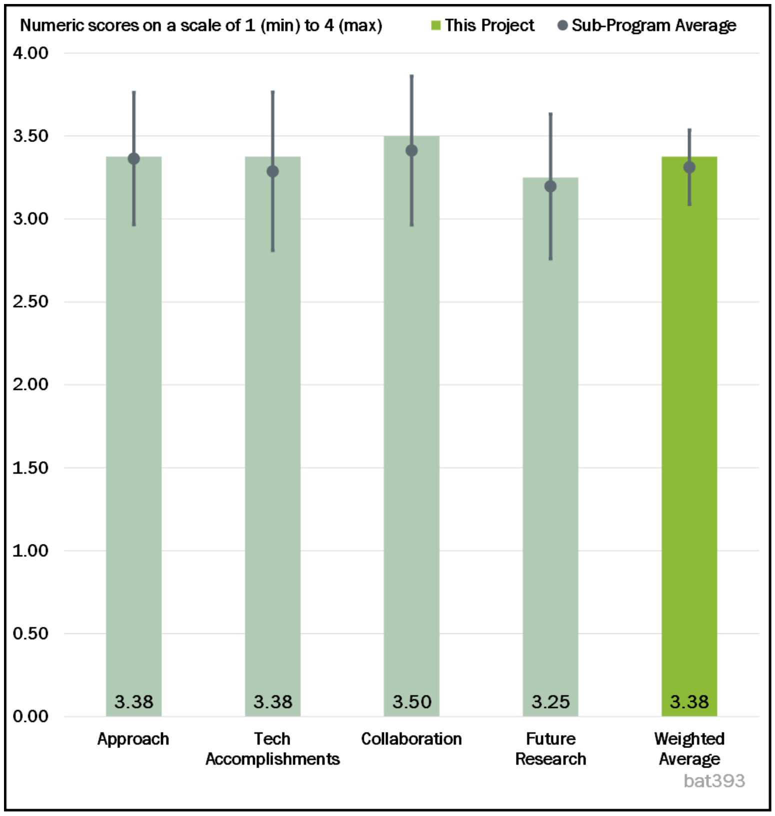

Figure 2-26 - Presentation Number: bat393 Presentation Title: Development of an Extreme Fast-Charging Battery Principal Investigator: Chao Wang-Yang (Penn State University)

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 seemed well designed to the reviewer and fairly feasible. Feasibility may depend on the development of new electrolytes and their applicability for thick electrodes. Going to very high temperatures to overcome challenges of thick electrodes likely will result in a tradeoff in cell lifetime.

Reviewer 2:

According to the reviewer, the approach is based on an asymmetric temperature modulation—charging at a high temperature (greater than 60ºC) to prevent Li plating and discharging at ambient temperatures. Li-intercalation kinetics at the anode seem to be accelerated at warm temperatures (60ºC), and the brief stay at the high temperature during fast charge (i.e., for ~10-min./cycle) does not seem to cause performance degradation. Self-heating is provided by a Ni foil inserted into the cell and connected to the third terminal, which is heated by power sources used for charging the cell.

One limitation of this technology is its invasive nature: i.e., the device is integrated into the cell. It would be better if such rapid heating can be achieved outside the cell, which will allow commercial cells to be used instead of focusing on cell optimization in this project with dense electrodes to provide high specific energy in combination with fast charging. The task is well oriented to improve fast-charge capability of Li-ion cells as required for EV batteries. The project is well integrated with other VTO projects.

Reviewer 3:

The technical approach addressed some key technical barriers related to battery fast charging in terms of charging methodology and cell design.

Reviewer 4:
The reviewer remarked that the approach for the test was well designed and feasible for the chosen test sample type. The test showed that heating up a large cell (35 Ah?) prior to a fast charge would improve the ability of the cell to accept a fast charge, without it negatively impacting cell life. This work however did not address concerns for doing this at a module or pack level or with the cell clamped. The addition of these test conditions is needed for technology evaluation.

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:
Progress toward the goal of improving fast-charge capability at the cell level was shown to be excellent. The overall impact on life for a high number of fast-charge events was better than expected. The additional cost of heating an entire pack and the time needed was not clear to the reviewer, however, and the effect of both could present issues.

Reviewer 2:
The demonstration of an improved electrolyte was encouraging to the reviewer. Questions might arise as to what cost that would add to the cell, which might hinder its acceptance. The performance has been verified independently, which is also encouraging. The tradeoff in cycle life is a large challenge to overcome.

Reviewer 3:
Good progress has been made in demonstrating the beneficial effect of preheating the cell with an internal device on the anode kinetics, improving the fast-charge capability of Li-ion cells without Li plating, and demonstrating good capacity retention during cycling, despite the brief exposure to warm temperatures. It was demonstrated that, with rapid preheating of less than 1 min. prior to charging, the cell gets to the optimum temperature to allow fast charging without plating. Gen-2 cells fabricated with denser electrodes showed improved specific energy and good cycling behavior at normal rates, but poor rate capability and poor performance with fast-charge cycling even after cell heating and need further development.

Modifications in the electrolyte have resulted in slightly improved performance under fast-charge cycling conditions, but the fade is still higher than desired. There are plans to modify the anode binder, but they have not been implemented yet.

The results are promising. It appears that this technology is more amenable to pouch cells. Can this be implemented in cylindrical cells? It would be more beneficial to collaborate with a commercial battery manufacturer to integrate this device in commercial cells so that this project can focus on improving fast-charge capability rather than specific energy. Overall, the progress achieved here is meaningful and relevant to DOE goals.

Reviewer 4:
The technical progress has been achieved as planned.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The collaboration to find a new electrolyte is an outstanding demonstration of working across organizations.

Reviewer 2:
The collaboration across the team members appeared excellent to the reviewer.

Reviewer 3:
There are good on-going collaborations with the faculty member from the same university and with the ANL researchers for developing new high-temperature electrolytes and also in evaluating the pouch cells. It may not

be too early to partner or collaborate with a commercial cell manufacturer for validating this approach in commercial high-energy cells.

Reviewer 4:
The appropriate teams were involved in this project to effectively demonstrate the intended technology for the identified sample type. The need for an appropriate vehicle module or vehicle battery for testing could require the addition of a vehicle manufacturer or a battery supplier to 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:
Significant challenges still remain relative to the Gen-2 cells with thick electrodes, which show serious Li plating, even with the modified electrolyte. Further improvements are desired in the high-temperature electrolyte. Future studies will focus on electrolytes with high diffusivity and transference number, electrolyte additives, or even cathode coatings for improved resilience at high temperatures. Future studies are planned effectively and are consistent with the objectives, according to the reviewer.

Reviewer 2:
The reviewer noted that figures on Slide 7 proved the validation of battery fast charging at 60˚C. For better comparison, the reviewer suggested studying conditions of 1C charge at 60˚C and 1C discharge at 27˚C to compare the impact of charging rate to battery life at high temperature.

On Slide 7, the cycle-life data with the same marked testing condition have different decay rates. Is there any typo in these testing conditions? Though it is not the major focus of this project, the reviewer hoped to see the PI talk with battery and charger industries for potential technology transitioning.

Reviewer 3:
The reviewer stated that battery pack and module testing for this technology approach is needed and appears to be identified as part of future plans.

Reviewer 4:
The proposed future research is very general and appropriate for increasing fast-charge capabilities. The reviewer suggested that perhaps something more specific to the method of this project should be included in future work.

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

Reviewer 1:
The overall objective is to enable rapid recharging of Li-ion batteries to a minimum of 80% SOC within 10 min. The strategy for achieving the fast-charge capability is based on heating the cell to 60^{o}C to improve anode kinetics. Related performance targets are to achieve high specific energy greater than or equal to 225 Wh/kg at the cell level and good cycle life greater than 1,000 cycles at 20% capacity fade in the cells accommodated with the self-heating scheme. Fast charging, which is being addressed here, is one of desired performance characteristics for EV batteries and will enable a widespread use of EV batteries, especially with higher specific energy and lower cost targeted here. The reviewer commented that the project is well designed and well planned and is consistent with the goals of the DOE-VTO program.

Reviewer 2:
The goal of the project is to develop fast charging of batteries using temperature modulation. According to the reviewer, this will lead to improved charging performance in line with DOE objectives.

Reviewer 3:
The project supports the goals for battery-charging-time reduction while the cell keeps reasonable high-specific energy density.

Reviewer 4:
Fast-charge capability is needed for the acceptance of the electric vehicle as a viable alternative to internal combustion (IC) powered vehicles.

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 funding seems to be about right considering the need for cell builds and the labor and equipment needed for experimental work.

Reviewer 2:
The resources are appropriate for the scope of the project.

Reviewer 3:
The resources appear to be sufficient for the proposed efforts.

Reviewer 4:
The resources are appropriate for the stated milestones.

Presentation Number: bat394
Presentation Title: Highly Ordered Hierarchical Anodes for Extreme Fast-Charging Batteries
Principal Investigator: Neil Dasgupta (University of Michigan)

Presenter

Neil Dasgupta, University of Michigan

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

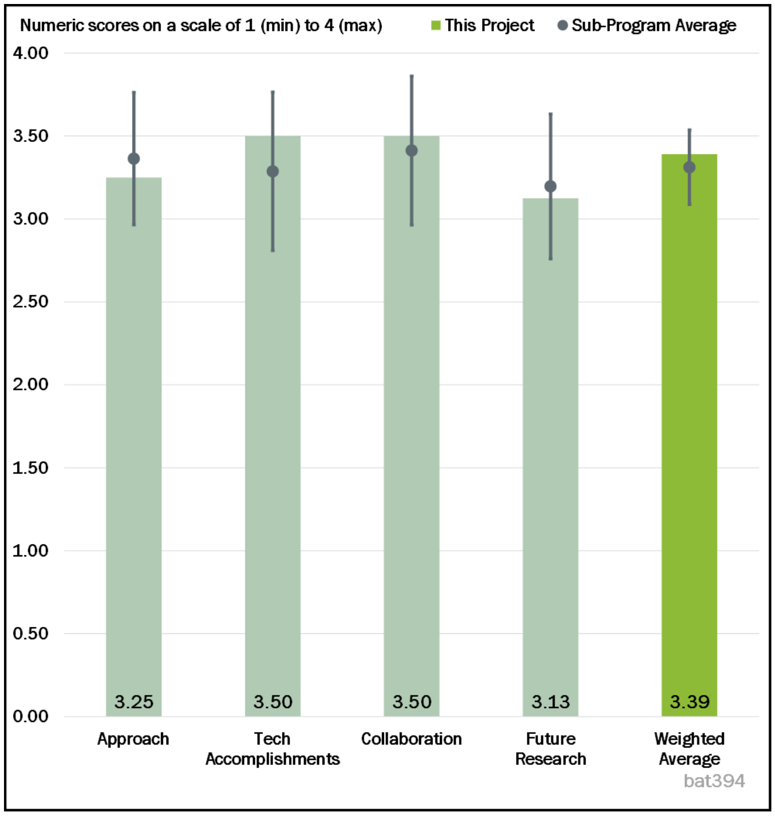

Figure 2-27 - Presentation Number: bat394 Presentation Title: Highly Ordered Hierarchical Anodes for Extreme Fast-Charging Batteries Principal Investigator: Neil Dasgupta (University of Michigan)

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 shows good proof of concept for the use of laser patterning of graphite electrodes to improve fast-charge capability of thick electrodes. The fast-charge objectives were met. The approach allows the existing infrastructure to remain with the addition of one processing step at the end.

Reviewer 2:

The project required a new method to increase fast-charge capability without increasing the possibility of Li plating, which negatively impacts life and performance. The work involved using lasers to create ordered holes in the anode layer. The technical barriers to do this work were addressed and the design was proven to be feasible.

Reviewer 3:

The approach is based on creating highly ordered laser-patterned electrodes to improve the permeability of Li ions deep inside the electrodes, which will reduce the anode polarization and improve its utilization during fast charge. To augment the experiential design of the anode, modeling studies were carried out to predict concentration gradients as a function of pore diameter and spacing. To directly examine the plating behavior, operando video microscopy has been used and confocal Raman imaging is being planned later. In addition to the modifying the bulk properties (porosities) of the anode, thin coatings of ionic conductor were applied on graphite anodes, though this is unconnected with the project objective of creating channels in the anode for enhanced Li^+ permeability.

Increasing the porosity (with low tortuosity as here) would no doubt benefit the high rate performance, but the reviewed said that there are a few adverse effects. More electrolyte will be needed to fill the pores, which will increase the cost and reduce the specific energy and energy density. Additionally, the increased surface area (which benefits here due to reduced current density at the anode) may result in higher irreversible capacity for SEI formation. Implementation of this in commercial cell electrode/cell fabrication processes will still be a challenge.

The task is well oriented to improve fast-charge capability of Li-ion cells, as required for EV batteries. The project is well integrated with other VTO projects.

Reviewer 4:
The technical approach addressed battery-cell design capable of fast charging with minimum cost increase. While the technical approach is impressive, the reviewer remarked that it is not unique. A similar approach was published by Habedank et al in *J. Electrochem. Soc.* 166 (16) A3940-A3949 (2019).

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 found the progress toward meeting the goals of the program to be excellent. The measured Li-plating issue was significantly reduced versus not using the method implemented, with little or no performance degradation.

Reviewer 2:
The reviewer noted that there are several publications indicating good progress in the scientific understanding and documentation of the results. Practically, the goals of the extreme fast-charge (XFC) program are met by this approach.

Reviewer 3:
Good progress has been made in demonstrating the benefits of laser-patterned channels in improving the anode utilization during fast charge, without the problem of Li plating from post-mortem analysis and in demonstrating the scalability of this process in 2 Ah cells. The reduced concertation polarization at the anode was verified by parameterized computational model. Finally, high-precision coulometry differential capacity (dV/dQ) analysis was used to track Li plating in the cells with control and modified anodes. The results are promising, but led the reviewer to make the following points:

- Even though there is an improvement in performance with this approach during XFC cycling, the specific energy and capacity retention of the test articles (2 Ah cells) is not impressive.
- Three-electrode cells with this highly ordered laser-patterned electrode (HOLE)-graphite anode will provide better understanding of the polarizations at the individual electrodes, if any such modifications are needed at the cathode also.
- It would be more beneficial to collaborate with a commercial battery manufacturer to validate this approach in commercial cells, instead of developing high-energy cells in a university set-up.

Overall, the progress achieved here is meaningful and relevant to DOE goals.

Reviewer 4:
The technical progress was made on plan.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Collaborations demonstrated with UM, several DOE National Laboratories, and international partners enabled access to unique capabilities, according to the reviewer.

Reviewer 2:
The reviewer found the team work to be well coordinated.

Reviewer 3:
The appropriate teams needed for the project were in place to meet the goals of the project. The collaboration between the teams was appropriate with each team making use of its specific strength.

Reviewer 4:
There are good, on-going collaborations with the DOE National Laboratories—SNL for high-precision coulometry and rapid EIS capabilities, ANL for providing electrodes for hole modification and later testing them, SLAC National Accelerator Lab for operando synchrotron XRD of HOLE electrodes during XFC—and ETH Zürich for X-ray tomography of HOLE electrodes.

The reviewer suggested that it may be useful to partner or collaborate with a commercial cell manufacturer for validating this approach in commercial high-energy cells, instead of attempting to optimize pouch-cell fabrication for achieving high specific energy.

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:
Scaling up to larger capacity cells is a good approach. Demonstration in a multi-cell pack would be of interest to the reviewer. Demonstration of the precision of the capacity achieved is needed for mass-scale manufacturing acceptance.

Reviewer 2:
Significant barriers remain relative to achieving industry-relevant, high-throughput processing for HOLE anode fabrication and for achieving high specific energy in pouch cells (250 Wh/hg), both of which the reviewer said pose considerable challenges. Future plans also include continued use of high-precision coulometry and rapid EIS to generate Li-plating markers and to implement confocal Raman scans of control and HOLE anodes for understanding the Li homogeneity in the anode. Future studies are planned effectively and are consistent with the objectives.

Reviewer 3:
The reviewer suggested that cost analysis should be done with laser partnering that includes anode materials loss and more electrolyte needed to fill the holes. What is the impact of laser patterning to volumetric energy-density impact?

Though successful in this project, fundamental detailed research is needed to better understand why laser patterning works (for example, electrochemical characterization, such as impedance spectra with and without laser patterning, may be needed) and analysis of how the hole laser patterning can help reduce the tortuosity to facilitate fast charging. Those may not be done due to time limitations. However, the reviewer suggested studying the optimization of hole size and number of holes per square unit of anode to understand their impact on battery life and energy density for optimization in the future.

Reviewer 4:
This project needs to justify the costs of implementation of this process over the cost of other processes that can perform the same task of putting structured holes in the anode layer. The process needs to demonstrate that the impact on the structure will not result in a reduction in the tensile strength or slow the speed of the overall layer-cell production speed, which has overall costs implications. There are some concerns that this process, while meeting the goals, could be less cost effective than some processes in place that accomplish the same result.

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

Reviewer 1:
This project is aimed at improving the fast-charge capability of Li-ion batteries to charge to greater than 80% of the cell capacity within 10 min. at room temperature, while retaining greater than 80% of initial specific energy of more than 180 Wh/kg over 500 fast-charge cycles. The strategy for achieving XFC capability is to modify the anode morphology with laser patterning to engineer highly regular, cylindrical-pore channels into post-calendared graphite anodes to facilitate permeability of Li ions deep into the anode. Such channeled pores will minimize concertation polarization both in the electrolyte and electrode (anode), reduce anode utilization, and can be implemented using a scalable process compatible with existing roll-to-roll manufacturing. Fast charging is one of desired performance characteristics for EV batteries and will enable a widespread use of EVs batteries, especially if the implementation has no adverse effect of cost or energy densities. According to the reviewer, the project is well designed and well planned and is consistent with the goals of the DOE-VTO program.

Reviewer 2:
There is a need to improve the fast-charge capabilities of vehicle battery systems. This process provides one way to improve the capability of a cell to be fast charged without negatively impacting the cell cycle life or performance.

Reviewer 3:
The project supports the goals for battery fast charging.

Reviewer 4:
The reviewer asserted that XFC objectives were met by this project.

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

Reviewer 1:
Resources seemed appropriate to the reviewer, considering the need to build cells and the labor required for experimentation.

Reviewer 2:
The resources are appropriate for the scope of the project.

Reviewer 3:
The resources appeared to the reviewer to be sufficient for the proposed efforts.

Reviewer 4:
The resources provided allow the project to meet its stated milestones within the timeframe identified.

Presentation Number: bat395
Presentation Title: Developing Safe, High-Energy, Fast-Charge Batteries for Automobiles
Principal Investigator: Wenjuan Mattis (Microvast, Inc.)

Presenter

Wenjuan Mattis, Microvast, Inc.

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

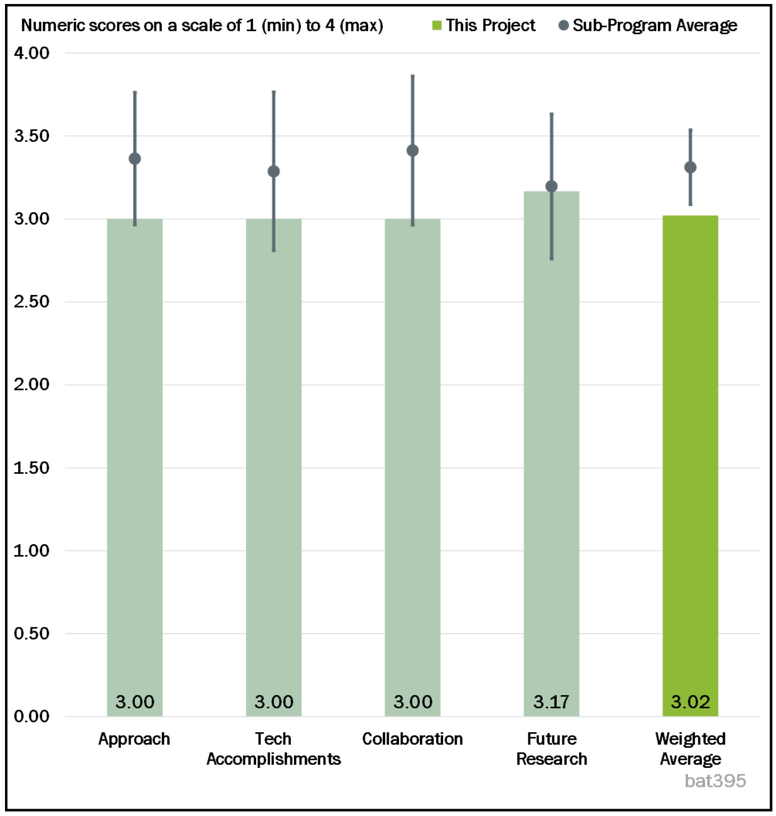

Figure 2-28 - Presentation Number: bat395 Presentation Title: Developing Safe, High-Energy, Fast-Charge Batteries for Automobiles Principal Investigator: Wenjuan Mattis (Microvast, Inc.)

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 technical approach addressed fast charging for high energy-density batteries.

Reviewer 2:
Gen-1 had decent fast charge capability. Gen-2 gave much higher energy density at low rates, but its performance was worst in terms of XFC. Perhaps more testing and modeling done prior to cell build to meet the target objectives might have been warranted. Results for Gen-3 appeared encouraging to the reviewer. There is very little emphasis on the anode, which is likely a problem for fast charge.

Reviewer 3:
It appeared to the reviewer that the approach has been focusing on improving the specific energy of Li-ion cells, while the fast-charge capability appears to be a secondary objective. The approach is based on developing new materials for XFC batteries—in particular, high-Ni, full-gradient composition NMC cathodes with and without low impedance electrolytes with selected additives—and incorporating them in automotive-size (larger than 15 Ah) XFC prototype cells. Detailed post-mortem studies were being made to understand the failures in XFC cycling. The nano-rod structure on the cathode surface is expected to improve kinetics (at the cathode). In addition, high-temperature stable separators were being targeted to improve the safety. Again, this is oriented to improve the specific energy rather than fast-charge capability of Li-ion cells.

It was pointed out in previous reviews that this project seems geared toward higher energy-density material improvements, which do not relate to fast charging, and the response and the results are not convincing. Unlike the other VTO projects that focused on enhancing the Li-intercalation kinetics at the graphite anode, this project has been focusing on the cathode with nano-rod surface morphology and surface coatings. As such, the project did not seem to the reviewer to be well integrated with other VTO projects.

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 technical progress is reasonable and is aligned with the plan.

Reviewer 2:
The reviewer found the performance in Gen-2 to be somewhat disappointing. Hopefully, Gen-3 will be successful, based on improvements in electrolyte and cathode material.

Reviewer 3:
Good progress has been made in achieving reasonably high (220 Wh/kg) pouch cells that retained 90% of capacity after 500 XFC cycles. The failure modes in the prototype cells during XFC cycling have been identified through detailed analytical studies, including TM dissolution from the cathode, which may be mitigated with surface stabilization of cathode with Mn-Al particles and electrolyte modification. As well, the high-Ni, full-concentration gradient cathode has been scaled up for prototype testing.

Even though there are clear advancements in cathode materials, and continuous improvement both in specific energy and cycling of prototype pouch cells, the reviewer stated that these improvements are not connected with the goal of improving fast-charge capability. The specific energies achieved here in the prototype cells are not significant compared to the commercial cells. Overall, the progress achieved here is only moderate and is relevant to DOE goals.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
According to the reviewer, there is active collaboration with ANL, where all the materials development (new cathode and electrolyte additives) and advanced characterization of materials and post-mortem electrodes were performed. Likewise, there is a successful industrial partnership with BMW in the fabrication of hard-can cells in the development of test protocols relevant to commercial EVS. Microvast will develop thermally stable separators to improve safety during XFC cycling.

Reviewer 2:
The collaboration across the team members appeared excellent to the reviewer.

Reviewer 3:
This is a good collaboration between a DOE National Laboratory and 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 future research finishes the cell build with new materials and tests the performance.

Reviewer 2:
There are continued challenges in identifying Li-plating conditions in XFC cells for implementing both material and engineering solutions and in overcoming the diffusional limitations during fast charge. Future plans include fabrication and testing of XFC automotive cells with high capacity by incorporating all the materials developed in this project. It was not clear to the reviewer what the targeted specific energy of the

cells is under nominal cycling conditions in relation to the current baseline cells, which can provide greater than or equal to 250 Wh/kg. Future studies are planned effectively and are consistent with the objectives.

Reviewer 3:
The reviewer commented that the aging study seems behind schedule. Testing with different upper charging voltage limits may be needed for the experimental cell design.

LiDFOB and lithium bis(oxalate)borate may be good additives for the electrolyte to reduce Mn dissolution. The reviewer suggested that other additives may be considered, such as 1% dimethylacetamide and MTMSC if the budget and time allow to do so in the future research.

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

Reviewer 1:
This project is aimed at developing safe, high-energy cells using new cathode and electrolyte materials with fast-charge capability and demonstrating XFC cells using both pouch and prismatic, large-format automotive cells. This project was intended to improve the understanding of cell failure during XFC cycling, which would enable EV cars to recharge at similar rates to gasoline vehicles and thus improve convenience for consumers. The reviewer noted that XFC-capable cells may accelerate adoption of EVs, especially for commercial fleet vehicles that could now run continuously. The project is well designed and well planned and is consistent with the goals of the DOE-VTO program.

Reviewer 2:
The project supports the goals for an increase in battery-specific energy density.

Reviewer 3:
The reviewer commented that this project does not seem to be overly targeted on XFC.

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 not overly funded and, considering the number of cells delivered, is appropriate.

Reviewer 2:
The resources appear to be sufficient for this project.

Reviewer 3:
The reviewer believed that resources are excessive for the project scope.

Presentation Number: bat396
Presentation Title: Enabling Extreme Fast Charging through Anode Modification
Principal Investigator: Esther Takeuchi (Stony Brook University)

Presenter

Esther Takeuchi, Stony Brook University

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

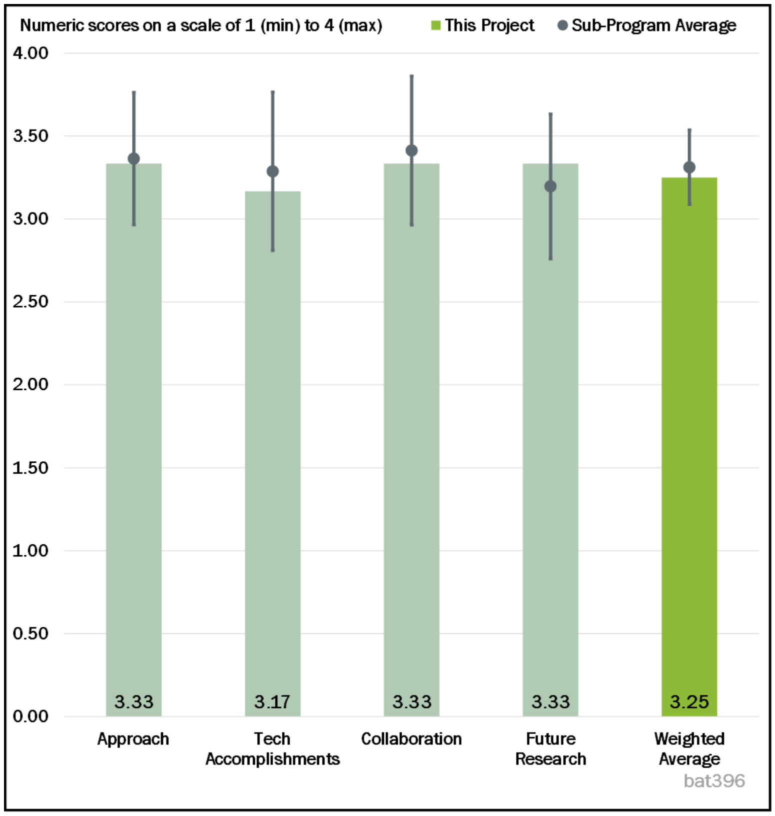

Figure 2-29 - Presentation Number: bat396 Presentation Title: Enabling Extreme Fast Charging through Anode Modification Principal Investigator: Esther Takeuchi (Stony Brook University)

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 demonstrated precise control of metal coatings that improved performance in terms of reduced performance fade and less Li plating. This targets some of the concerns with fast charging. According to the reviewer, the project was a nice demonstration of the concept to increase Li deposition over-potential.

Reviewer 2:

This project is addressing the barriers of extreme fast charging for EVs and is based on the concept of selectively increasing the over-potential for Li deposition at the graphite surface through electrode-surface treatment with nanometer-scale Cu or Ni films. It was not quite clear to the reviewer how this seems to be working, i.e., if Li is reduced as a metal and diffuses through the Cu or Ni layer. If so, this is bypassing the intercalation, which would be the desired reaction on the graphite anode versus plating. With the volume changes occurring in the graphite anode, it is quite possible that the coating will delaminate during cycling. Possibly coating the particles may be a better alternative. This concept, if successful, is relatively easier to implement and is compatible with current manufacturing methods. Also, verification of this concept is fairly straightforward, with nanometer-scale Ni or Cu layers with optimized thickness on graphite and evaluating the fast-charge characteristics in relation to the baseline.

Detailed surface studies were made to understand the SEI characteristics of the pristine graphite and the Ni- or Cu-coated graphite anodes and to quantify Li deposition on these anodes during fact charging. Even though this concept is easier to implement in practical cells, the effect will not be significant, with only 40 millivolts (mV) and 30 mV of over-potentials for Li deposition on Cu and Ni. Typical anode polarization during fast charging is much higher. This is substantiated by the fact there is considerable Li plating (no doubt less) even on Cu- or Ni-coated graphite anodes. With the coated graphite anodes at optimized thickness, 2 Ah cells will be fabricated and delivered to a DOE National Laboratory for assessment.

Overall, the reviewer commented that the project has been addressing the technical barriers related to fast charging, is well-designed, appears feasible, and may be integrated with other VTO efforts.

Reviewer 3:
The technical approach addressed battery fast charging by anode coating with Cu and Ni.

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 technical approach is innovative, and the progress is aligned with the plan.

Reviewer 2:
Good progress has been made in verifying this concept showing reduced Li plating on Ni- and Cu-coated graphite, even though Li plating is not totally suppressed. The type and thickness of the coating were optimized. Detailed studies were made to characterize the surface coating and mainly the SEI that formed on the coated anode, which seems to be similar to the SEI on baseline graphite anodes. The benefit of coated graphite anode was demonstrated with Ni-graphite anodes in single-layer pouch cells on reducing capacity fade, and a 2 Ah cell build containing the coated anodes is being planned. The reviewer opined that it would be interesting to see the three-electrode cell data with different anodes (coated and pristine) to correlate the anode over-potential with the extent of Li plating.

Overall, the progress achieved is reasonable and well directed toward the DOE goals of developing LIBs with high specific energy and good capacity retention during XFC cycling.

Reviewer 3:
At this funding level, the reviewer asserted that one might expect a little more progress. The project did, however, lead to proof of concept in terms of reducing the amount of Li plated and increasing the cell life, which might have a universal applicability not just for XFC. The metal coatings do not increase the charge capability though they do not negatively affect it either.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The collaboration across the team members appeared excellent to the reviewer.

Reviewer 2:
The project demonstrates use of resources and expertise across the partner team.

Reviewer 3:
This is a joint program between Stony Brook University and BNL for achieving Cu-Ni coatings and basic electrochemical measurements at the university and extensive characterization studies and cell characterization at the National Laboratory. Plans are underway to collaborate with NREL for computational efforts. The reviewer remarked that collaboration with a cell manufacturer will possibly expedite the development toward demonstration in high specific-energy cells.

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 is on target to accomplish the program objectives.

Reviewer 2:
There are still challenges in understanding the over-potential of surface-treated versus control anodes as a function of charge rate and understanding capacity retention for Cu- and Ni-coated electrodes. Also, the uniformity of the metal coatings will need to be verified using SEM and EDS. In short, the investigations on Li-plating on Ni- or Cu-graphite will be completed under different experimental conditions before finally planning for 2 Ah cells with graphite anodes with optimized metallic coatings for DOE assessment.

Overall, the reviewer indicated that the planned future work is logical and leads to the realization of the proposed technology.

Reviewer 3:
A cost analysis with the developed coating technology for cell production may help to convince battery producers to consider technology transfer. Now that the temperature seems to improve battery capacity at relatively high temperatures (Slide 15), the reviewer suggested that it may be worth the effort to test battery decay for fast charging at higher temperatures (e.g., 50˚C) with the developed cells.

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

Reviewer 1:
This project is aimed at improving extreme fast charging by changing the over-potential for Li deposition at the graphite surface through electrode-surface treatment with nanometer-scale Cu or Ni films. The surface coatings will increase the over-potential for Li nucleation and growth and suppress Li deposition at high charge rates; the battery will address the EERE goal (500 6C charge at 1C discharge cycles) without much design modifications to the current Li-ion cells. If successful, this project will enable EV cars to recharge at similar rates to gasoline vehicles and may accelerate adoption of EVs, especially for commercial fleet vehicles. According to the reviewer, the project is well designed and well planned and is consistent with the goals of the DOE-VTO program.

Reviewer 2:
Since Li plating is a very strong concern for XFC, the reviewer asserted that this project is right on target.

Reviewer 3:
The project supports the goal of fast charging for the battery with relatively high specific energy 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 appear to the reviewer to be sufficient for the proposed efforts.

Reviewer 2:
It would be good to see more published results at the end of this project. Presumably that will follow after completion of the Q8 milestones.

Reviewer 3:
The resources, the reviewer believed, are excessive for the scope of the project.

Presentation Number: bat397
Presentation Title: Titanium Niobium Oxide-Based Lithium-Ion Batteries for Extreme Fast-Charging Applications
Principal Investigator: Sheng Dai (University of Tennessee at Knoxville)

Presenter

Sheng Dai, University of Tennessee at Knoxville

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

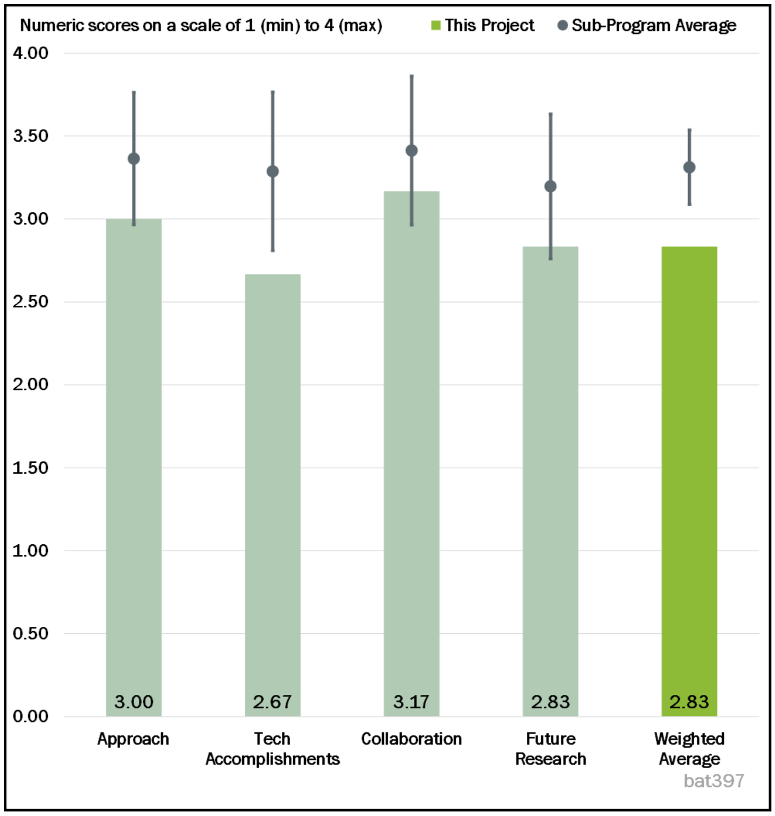

Figure 2-30 - Presentation Number: bat397 Presentation Title: Titanium Niobium Oxide-Based Lithium-Ion Batteries for Extreme Fast-Charging Applications Principal Investigator: Sheng Dai (University of Tennessee at Knoxville)

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 technical barriers as envisioned at the beginning by looking at doping and carbon and loading of titanium niobium oxide (TNO).

Reviewer 2:

The technical approach addressed battery fast charging by employing a TNO anode.

Reviewer 3:

This project is attempting to find alternative anode material to overcome the problem of Li plating at high-charge rates. Specifically, TNO with high capacity (250 mAh/g) is being developed, with improved electronic conductivity by metal doping and carbon coating. The approach involves developing methods to synthesize large-scale TNO and demonstrating its cycle life in full NMC622 cathodes using suitable electrolyte additives (new Li malonatoborate salts) in fast charge cycling (XFC). Even though there is an improvement in the capacity of the TNO anode, its capacity is still lower than graphite at nominal rates and, more importantly, its voltage is quite high at more than 1.2 V, about 1 V higher than graphite. With the high anode potential (low cell voltage) and low capacity, the reviewer stated that it is unreasonable to expect high specific energy for this system, as also pointed out in the previous reviews. Even though the TNO anode supports fast charging with minimum polarization (relative to the cathode), the specific energy during XFC cycling is woefully low (130 Wh/kg) and well short of the DOE target.

Overall, the project aims to address the technical barrier of the low energy of Li-ion cells during fast-charge cycling, but is not an appropriate solution, according to the reviewer, and may not be integrated with other VTO efforts in this category.

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:
In light of the funding level, the reviewer said that the accomplishments and progress are good.

Reviewer 2:
The technical progress is reasonable though some milestones have been delayed. The developed cell may have potential for high-power applications though its specific energy density cannot meet 180 Wh/kg.

Reviewer 3:
Moderate progress has been made in developing the TNO anode as an alternative for enhancing the fast-charge capability of Li-ion cells. Bulk TNO was successfully synthesized without using a templating agent, which provides high specific capacities of 250-300 mAh/g, especially after modification (not mentioned what this is). The electronic conductivity for high-rate performance was improved with different dopants (such as TM doping, Li doping, TM and Li co-doping, and C doping) and coatings. With the modified and doped TNO in three-electrode cells with the NMC622 cathode, the team demonstrated that the anode polarization during fast charge is low compared to the cathode. Finally, large-format 2-Ah pouch cells were fabricated, evaluated, and delivered to DOE using this material.

Even though there is a decent amount of improvement in the TNO anode, the reviewer observed that the overall performance is inadequate, and the specific energy is barely 130 Wh/kg versus the DOE target of 180 Wh/kg. Especially because of the high anode potentials and low cell voltages, the reviewer said that it is very unlikely that the DOE target can be met with this material.

Overall, the progress achieved is reasonable and well directed toward DOE goals, but the improvement in the fast- charge capability is achieved with a severe penalty in the specific energy. Even if it is possible to get to 180 Wh/kg under XFC cycling, the specific energies under nominal cycling conditions will be significantly lower than the current Li-ion batteries.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The project appeared to the reviewer to have good collaboration between a National Laboratory and materials suppliers.

Reviewer 2:
The contractor has put together a team consisted of a university and a National Laboratory doing collaboration to attack the technical barriers for cell design capable of fast charging. A further collaboration with National Laboratories and/or industry may be needed to increase cell-specific energy density and cell life, according to the reviewer.

Reviewer 3:
Most of the work in this project—including development of TNO material and electrolyte, battery evaluation, and fabrication and testing of large format pouch cells—is being done at the PI's organization (ORNL). The reviewer saw little collaboration with the material suppliers, TODA America and Conoco Phillips, for NMC622 powders and conductive carbon and also suppliers for the binder polymer.

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 hoped to see if a high-energy cathode can be included for higher, cell-specific energy density if there is future research conducted in this direction with TNO anodes.

Reviewer 2:
Unlike other projects, this project has a unique challenge of having to synthesize the anode material in bulk for large- format pouch cells. Additionally, the reviewer emphasized that there is a bigger challenge of low energy density, well below the DOE target because of the low cell voltages. Future work will aim to improve the specific capacity of TNO under high rates using anion doping and substituting for Nb to increase the cell voltage with high-voltage cathodes and to mitigate the gassing with surface coatings. Overall, the planned future work is logical, though it may not lead to the realization of DOE's performance targets for XFC cycling of Li-ion batteries.

Reviewer 3:
Gassing is an important subject to address. Understanding its formation is the first step as laid out by the investigators. Doping strategies might be helpful to improve rates but probably not a great return on investment. Doping to change the voltage is also unlikely to be useful, according to the reviewer.

Volumetric energy density could be an important benefit of TNO. Perhaps use of larger particles is worthwhile to increase this advantage. This technology will never be a leader in terms of specific energy density.

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

Reviewer 1:
This project is aimed at improving extreme fast charging by developing alternative anode material to graphite, which is susceptible to Li plating due to the proximity of its potential to Li deposition potential. According to the reviewer, specific objectives are to:

- Develop TNO-based anode materials with high electronic conductivity, high Li diffusivity, and high capacity to meet the requirements of 180 Wh/kg during fast charge (6C) (XFC) cycling.
- Identify new electrolyte additives for good capacity retention (80%) through 500 XFC cycles.

If successful, this project will enable EV cars to recharge at similar rates to gasoline vehicles and may accelerate adoption of EVs, especially for commercial fleet vehicles.

The reviewer stated that the project is well designed and well planned and is consistent with the goals of the DOE-VTO program.

Reviewer 2:
The project supports the goals for battery fast charging.

Reviewer 3:
Using a TNO anode can enable fast charging. The reviewer noted that it is likely difficult to adopt for pure EV owing to lower energy density, but there could be other applications.

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 scope of the project

Reviewer 2:
The resources appear to be sufficient for the proposed efforts.

Reviewer 3:
The reviewer remarked that there is a very small amount of funding considering that full cell builds are done.

Presentation Number: bat398
Presentation Title: Extreme Fast-Charging Lithium-Ion Batteries
Principal Investigator: Edward Buiel (Edward Buiel Consulting, LLC)

Presenter

Edward Buiel, Edward Buiel Consulting, LLC

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

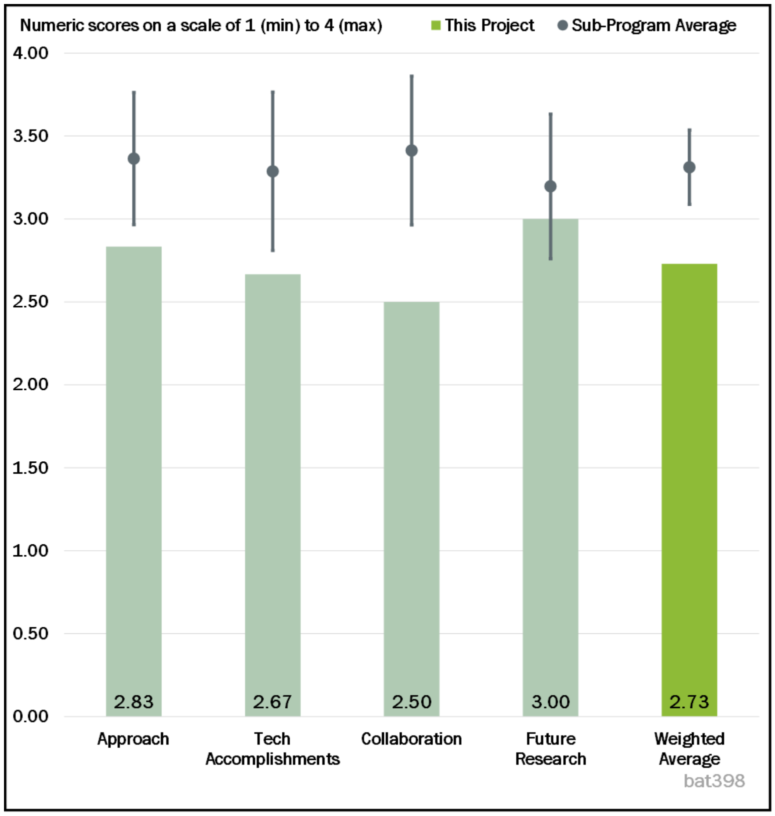

Figure 2-31 - Presentation Number: bat398 Presentation Title: Extreme Fast-Charging Lithium-Ion Batteries Principal Investigator: Edward Buiel (Edward Buiel Consulting, LLC)

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:

Investigators are able to achieve the XFC goals by engineering the anode thickness and choice of electrolyte and cathode. Based on the results, the reviewer commented that the approach is sound and well designed.

Reviewer 2:

The technical approach is appropriate.

Reviewer 3:

This project is attempting to find optimum anode, cathode, and electrolyte compositions and also the cell design to improve specific energy while enabling fast-charge capability. Capacity loss and impedance increase after 350 h were used as diagnostic means for Li plating, as the cells were cycled at various rates from C/10 to 4C. Multiple anode compositions (details not provided on these variations) were combined with two different cathodes: nickel cobalt aluminum oxide (NCA) and NMC622. Cell designs were closely examined to understand the role of tabs in causing non-uniform current distribution and heat dissipation at high charge rates, and new electrode designs were pursued to minimize the tab effects.

This project did not seem to the reviewer to have a clear strategy for the different anode, cathode, and cell variations examined here or was not presented well. Overall, the project aims to address the technical barrier of the low energy of Li-ion cells during fast charge cycling but is not particularly informative and revealing to be integrated with other VTO efforts in this category.

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, high-rate charging was accomplished per the objective of the project by modifications of the cell chemistry and cell design.

Reviewer 2:
The technical achievement is impressive, but the reviewer said that there is still a gap for the designed cell to meet the specific energy density goal.

Reviewer 3:
Moderate progress has been made in developing the fast-charge capability of Li-ion cylindrical cells by examining multiple anode and cathode variations and cell-design modifications. Capacity loss and impedance increase after 350 h were identified as a diagnostic means for Li plating, as the cells were cycled at various rates from C/10 to 4C. Multiple cells produced with different anode compositions showed limited effect of anode composition on charge rate.

Subsequent variations included reduced anode-coating weight and increased anode density, which resulted in higher charge rates of 6C in Gen-2.5 power cells consistent with DOE XFC test conditions. Further reduction in the anode- coating weight improved the fast charge capacity to 9C in Gen-3 cells. Modified electrode design mitigated the impact of tab location on uniformity in current distribution of heat dissipation. Addition of SiO_x to the anode did not improve the performance in Gen-3 cells.

Overall, the progress achieved is reasonable and directed toward DOE fast-charge goal, but there is no mention of the specific energies from the cells with variations. It was not clear to the reviewer that these cells meet the DOE goals in specific energy, i.e., 180 Wh/kg in XFC cycling with 80% retained through 500 cycles (and high specific energy at nominal rates).

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented that the project could have benefited from some collaborators with analytical tools and expertise not available to the investigators.

Reviewer 2:
This is a project from Coulometrics LLC with no partners in the project execution.

Reviewer 3:
According to the reviewer, the team would have been strengthened if it had teamed with at least one National Laboratory and/or an established battery OEM to choose appropriate cathode-anode pair and cell format to increase cell specific energy density.

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 final research meets the program objectives.

Reviewer 2:
The project is coming to an end and the only remaining activity is to complete full-cell homologation of proven design improvements for the final report and deliver cells for DOE evaluation.

Reviewer 3:
The reviewer remarked that there is no action proposed in the future plan to meet the proposed cell energy-density goal.

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

Reviewer 1:
The objective of fast charging Li-ion was achieved.

Reviewer 2:
This project is aimed at improving fast-charging lithium-ion batteries (LIBs) and identifying methods to overcome Li plating on the anode without sacrificing energy density. Specifically, this project has addressed XFS by optimizing the compositions of anode, cathode, and electrolyte anode composition, as well as the cylindrical (18650) cell design. If successful, this project will enable EV cars to recharge at similar rates to gasoline vehicles and may accelerate adoption of EVs, especially for commercial fleet vehicles.

The reviewer stated that the project is well designed and well planned and is consistent with the goals of the DOE-VTO program.

Reviewer 3:
The overall goal of this project supports battery fast-charging research, in the reviewer's opinion.

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 scope of the project.

Reviewer 2:
The funding level is appropriate for the research.

Reviewer 3:
Resources appeared to the reviewer to be excessive based on the project plan but might be okay if a large number of cells were built.

Presentation Number: bat400
Presentation Title: Novel Liquid/Oligomer Hybrid Electrolyte with High Lithium-Ion Transference Number (Hi-LiT) for Extreme Fast Charging
Principal Investigator: Zhijia Du (Oak Ridge National Laboratory)

Presenter

Zhijia Du, Oak Ridge National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

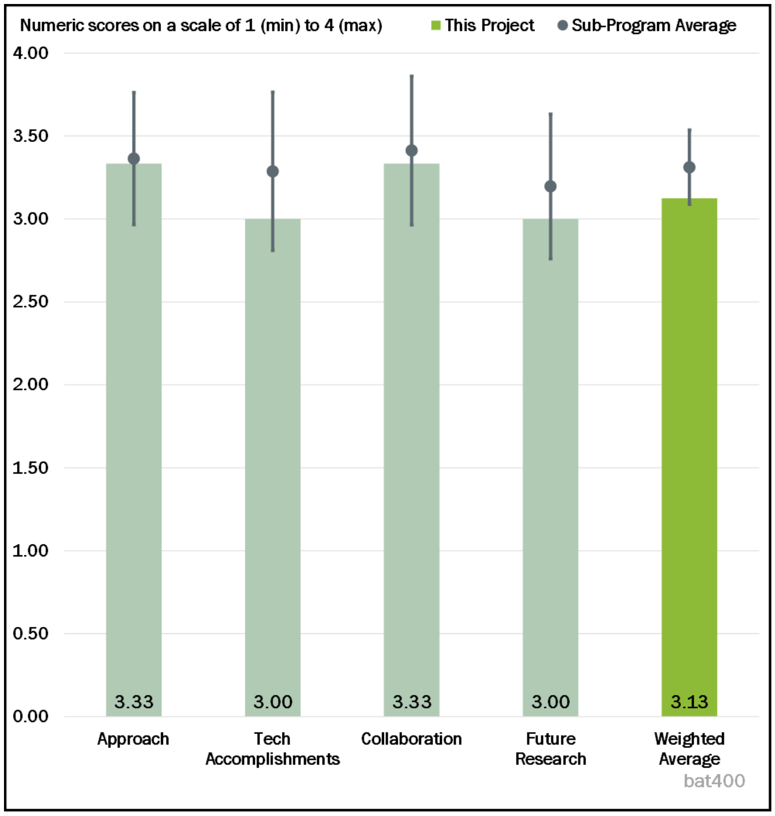

Figure 2-32 - Presentation Number: bat400 Presentation Title: Novel Liquid/Oligomer Hybrid Electrolyte with High Lithium-Ion Transference Number (Hi-LiT) for Extreme Fast Charging Principal Investigator: Zhijia Du (Oak Ridge National Laboratory)

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:

This project is aimed at developing an electrolyte with high transference number for Li-ions and high conductivity to minimize their concentration gradient and improve fast-charge cycling, with the underlying assumption that the Li-ion depletion at the interface is responsible for the low anode efficiency and low specific energy during fast charging. The approach involved the use of different salts (e.g., lithium bis(fluorosulfonyl)imide [LiFSI] and other novel Li salts to slow anion mobility), the use of multi-component solvents to reduce electrochemical (EC)-complexation with Li^+, and the use of electrolyte additives to further immobilize anions, dissociate cations in the electrolyte, and improve their transference number. In order to mitigate the problem of Al corrosion from the imide salt, another protective additive was developed. There is an improvement in the conductivity and in the transference number with the imide salt compared to $LiPF_6$, but the solutions with anion oligomers have lower conductivity to offset the anticipated increase in the transference number. Based on the above considerations, the expected improvement here in fast-charge capability combined with high specific energy will be marginal.

Overall, the project aims to address the technical barrier of the low energy of Li-ion cells during fast-charge cycling. The reviewer said that the project is well designed and feasible and may be integrated with other VTO efforts in this category.

Reviewer 2:
The reviewer called the experimental program well designed. Understanding differences in transference number is important for fast charging. Some method to rapidly screen might be appropriate to find additives and new salts.

Reviewer 3:
The technical approach aims at battery fast charging with novel electrolyte 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 indicated that the technical progress is impressive and is aligned with the plan.

Reviewer 2:
Investigators made substantial progress and identified LiFSI as a promising alternative for XFC. There is good documentation of results through publications, according to the reviewer.

Reviewer 3:
The reviewer commented that good progress has been made in demonstrating improved fast-charge capability with electrolyte-containing LiTFSI salt and additive to mitigate Al corrosion. Possibly the increase in the cell temperature during fast charge favors the LiTFSI salt over $LiPF_6$. Optimum salt concentration was identified (1.5 molarity [M]) both for fast-charge capability and capacity retention during XFC cycling. The 0.5 Ah pouch cells containing the ORNL electrolyte formulation had higher energy density and better capacity retention than the baseline Gen-2 electrolyte. Projected energy densities to 50 Ah meet the DOE goals but are yet to be demonstrated in large-enough cells. Also, a good baseline would be a commercial EV cell, both in terms of specific energy during XFC cycling and normal cycling rates, rather than a laboratory pouch cell with a Gen-2 electrolyte. The gain in the transference number (not shown here) with the addition of anion oligomers will be offset by the reduction in the conductivity.
Overall, the progress achieved is reasonable but not to the expected level as the project is completing this year.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The team worked well together to obtain results utilizing expertise across institutions.

Reviewer 2:
The reviewed noted that there are several collaborators on this project, which is led by ORNL: another DOE National Laboratory (ANL), multiple universities (University of Alabama at Huntsville, Virginia Tech, and Purdue University), and also a partner in XALT Energy.

Reviewer 3:
The collaboration across the team members appeared sufficient to the 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:
It was not clear to the reviewer why testing of oligomer salt is proposed since it has lower performance relative to LiFSI. Other than that, the proposed work is on target to accomplish project objectives.

Reviewer 2:
There are a few outstanding activities to be completed in the next few months, which include evaluating more electrolyte additives and Li oligomer salts during fast charge; repeating with higher electrode loadings with the new electrolyte; performing post-mortem on the cycled cells for Li plating; and completing the deliverable of 2 Ah cells. Overall, the reviewer described this project as well aligned with DOE goals, but the progress achieved toward these goals is only moderate.

Reviewer 3:
Lithium plating seems to be not the only problems causing cell-capacity decay. A cell with 1.5 M molarity seems to have more Li plating but has less capacity decay compared to those with 1.75 M and 2.0 M (Slides 9 and 10). This may be due to electrolyte decomposition or resistance change with different LIFSI molarity and additive.

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

Reviewer 1:
Electrolyte is important to XFC cells. This project identified new formulations with improved performance toward the objective.

Reviewer 2:
This project is aimed at developing a new electrolyte for Li-ion cells with high transference number for Li ions to minimize the Li^{+}-ion concentration gradient during fast charging. Specifically, the target is to develop an electrolyte wherein the transference number is increased from 0.36 to 0.75, while maintaining a relatively high conductivity of 4-10 mS/cm. With this electrolyte, it was expected that the realized specific energy could reach 180 Wh/kg and at least 80% of that is retained after 500 fast-charge cycles. If successful, this project will enable EV cars to recharge at similar rates to gasoline vehicles and may accelerate adoption of EVs, especially for commercial fleet vehicles.

The reviewer indicated that the project is well designed and is consistent with the goals of the DOE-VTO program.

Reviewer 3:
The project supports the goal of fast charging for the battery with relatively high, specific energy density.

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 resources are about right.

Reviewer 2:
The resources are sufficient for the scope of the project.

Reviewer 3:
The funding level for this project is appropriate, according to the reviewer.

Presentation Number: bat401
Presentation Title: Advanced Electrolytes for Extreme Fast Charging
Principal Investigator: William Chueh (Stanford University)

Presenter

William Chueh, Stanford University

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

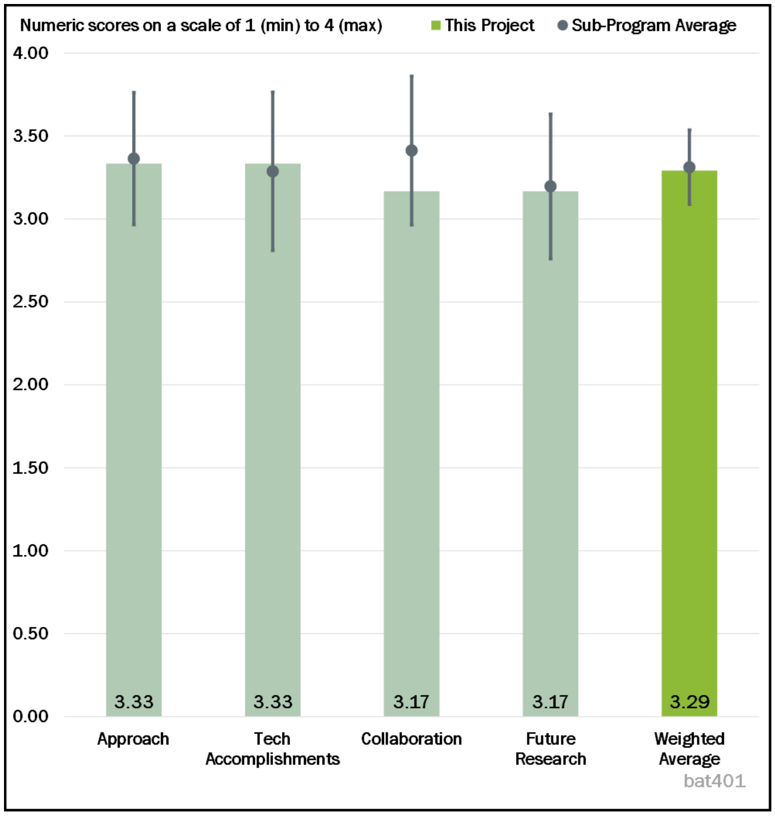

Figure 2-33 – Presentation Number: bat401 Presentation Title: Advanced Electrolytes for Extreme Fast Charging Principal Investigator: William Chueh (Stanford University)

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 technical approach addressed battery fast charging with an advanced electrolyte and four-step charging protocol.

Reviewer 2:

This project is aimed at developing an advanced electrolyte that can enable fast charging at 6C without the complications of Li plating at the anode, which is detrimental to its subsequent performance. Additionally, the charging protocol is being optimized, and the effects of fast-charge cycling on the electrodes are being analyzed using in-situ X-ray and ex-situ cryo-EM characterization. Electrolyte improvement is based on modifying the electrolyte bulk properties, including conductivity, desolvation kinetics using co-solvents (methyl acetate), and modifying the interfacial (SEI) properties using additives (FEC and two other additives).

It was not clear to the reviewer what the rate-determining step is, i.e., desolvation kinetics or diffusion across the SEI and to what extent desolvation kinetics are improved with the methyl acetate (MA) co-solvents. Electrolytes with MA additions have poor high-temperature resilience, which may be a factor during fast charging. X-ray microscopy and diffraction were used for detecting Li plating, and cryo-EM was adopted to probe the location of Li plating and understand SEI. In parallel, simulations were made for the voltage profile during fast charge.

The approach adopted here is fairly routine and lacks sufficient novelty in terms of electrolyte modifications. Overall, the project aims to address the technical barrier of the low energy of Li-ion cells during fast-charge cycling. According to the reviewer, the project looks well designed and feasible and may be integrated with other VTO efforts in this category.

Reviewer 3:
The project has shown steady improvement in improving fast-charge acceptance and is nearing the goal at about the half-way mark of the project. Li plating is observed on the graphite.

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 project has met the technical goals and is aligned with the plan.

Reviewer 2:
The project is on track in terms of improved rate acceptance. Li plating has been observed. The reviewer suggested that perhaps more documentation of the results should be done in the literature.

Reviewer 3:
The reviewer found that good progress has been made in demonstrating improved fast-charge capability with electrolyte modifications by using MA co-solvent, FEC, and other electrolyte additives and higher concentrations of salt. With these modifications, the percentage-charge capacity is close but short of the DOE target. Interestingly, the baseline electrolyte was made to look much worse than it should be, which makes the improvement more significant for the modified electrolyte. The use of MA co-solvent will hurt the high-temperature (55ºC) resilience of the batteries, which is also a performance requirement for EV batteries. Both XRD microscopy and cryo-EM were used to study Li plating and SEI formation, though it was not quite clear to the reviewer what additional insight was gathered. It was inferred that the electrolyte mass transport is no longer limiting cell performance, which is not consistent with many of the other fast-charge efforts where enhanced Li transport in the electrolyte has been shown to improved fast-charge capability.

Overall, the reviewer noted that the progress achieved is reasonable around the midpoint of this project.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer asserted that the collaboration across the team members is excellent.

Reviewer 2:
There are collaborations within the lead organization (Stanford University) and the Stanford Synchrotron Radiation Lightsource, along with the ANL Advanced Photon Source, and Dr. Koch from Covalent Associates, one of veterans in the field of Li-ion battery electrolytes.

Reviewer 3:
The reviewer noted that the expertise of the various collaborators has been utilized to build cells, measure their performance, model the cells, develop new electrolyte formulations, and do analytical work on the graphite anode to show Li plating.

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:
There are a few challenges in the next year, i.e., to translate single-layer performance and cycle life to multi-layer cells. Future studies will therefore focus on optimizing the charge protocol to improve 6C charging,

utilizing X-ray and electron characterizations to assess electrolyte effects on SEI thickness and lithium plating during fast charging, and optimizing the rate capability and cycle life in multi-layer cells.

Overall, the reviewer found that the future work is logical and addresses one of the technological barriers of Li-ion batteries, i.e., fast charge with high percentage capacity (80%) and good capacity retention (80%) through 500 XFC cycles, consistent with DOE goals.

Reviewer 2:
The reviewer suggested that some effort to reduce Li plating should also be included.

Reviewer 3:
The reviewer commented that cell Wh/kg change with cycle life should have been provided to illustrate the research progress. Additionally, it is suggested the impedance data be provided to show the conclusion that increased impedance is responsible for capacity decay.

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

Reviewer 1:
The project is targeted toward the program goals to achieve XFC.

Reviewer 2:
This project is aimed at developing an advanced electrolyte and identifying suitable charging protocols that enable XFC on thick graphite-based anodes. With the need for high specific energies, the electrodes in Li-ion cells tend to be thicker and dense, which also pose a significant barrier to XFC (6C) also required for EV batteries. At these high charge rates, there is a greater propensity for Li plating, which leads to a rapid performance decay. It is thus challenging to realize 180 Wh/kg during fast charge and to retain 80% after 500 fast-charge cycles. If successful, this project will enable EV cars to recharge at similar rates to gasoline vehicles and may accelerate adoption of EVs, especially for commercial fleet vehicles.

According to the reviewer, the project is well designed and is consistent with the goals of the DOE battery program.

Reviewer 3:
The project supports the goal of fast charging with the designed high-energy-density cell.

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

Reviewer 1:
Considering the number of cells built and the work done, the resources seemed appropriate to the reviewer.

Reviewer 2:
The funding resources appear to be appropriate for the proposed efforts.

Reviewer 3:
The reviewer found the resources to be excessive for the scope of the project.

Presentation Number: bat404
Presentation Title: Direct Fluorination of Disordered Rock Salt Cathode Oxides: Synthesis and Characterization
Principal Investigator: Jagit Nanda (Oak Ridge National Laboratory)

Presenter

Jagit Nanda, Oak Ridge National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

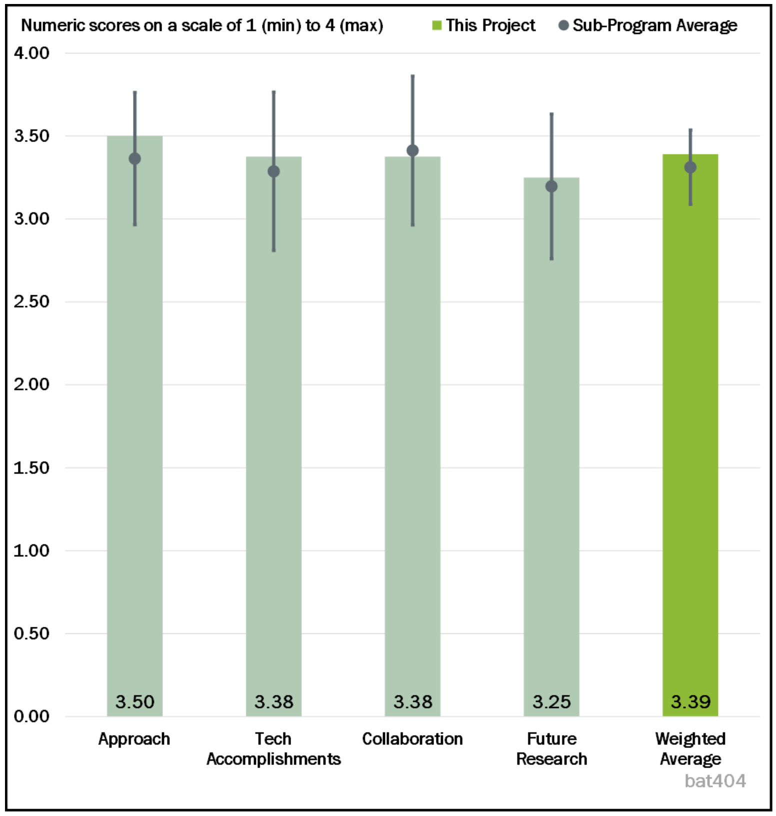

Figure 2-34 - Presentation Number: bat404 Presentation Title: Direct Fluorination of Disordered Rock Salt Cathode Oxides : Synthesis and Characterization Principal Investigator: Jagit Nanda (Oak Ridge National Laboratory)

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:

Direct fluorination of DRX cathode oxides is an interesting new approach, according to the reviewer.

Reviewer 2:

The project team has presented a variety of possibilities of incorporating F into the DRX cathode structure. It has done excellent work identifying surface F (LiF films) versus bulk (oxyfluoride) and correlating those analytical results with electrochemical performance. The approach combines synthesis and optimization of DRX powders with and without F with strong emphasis on analytical characterization.

Reviewer 3:

The team addressed the solid background, approach, and strategy to explore F-DRX materials. The reviewer commented that direct fluorination is an innovative and challenging approach. Based on the presentation, there are three different approaches to enhance the F content. The reviewer said that it would be good to design a matrix to evaluate the input synthesis methods and output characterization and performance variables to understand the fluorination impact.

Reviewer 4:

The PIs address important barriers to the high-density, cobalt-free cathode. The group has devised scalable synthesis followed by F solubility optimization. Rock salt is a stable crystal structure with likely high stability.

However, the reviewer asserted that the use of Nb-type, rare-earth materials is questionable. This year the group has focused on Ti.

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 identified a variety of routes, such as direct fluorination of TM oxides as precursors for DRX powders versus direct fluorination of DRX powders. Synthetic variables to incorporate F into the DRX cathode powders were also analyzed. The reviewer commented that one interesting finding was that short-range ordering induced by F content could play a role in Li transport. The NMR results that can clearly identify the LiF surface signal were important. Similar results were confirmed with EM and electron energy loss spectroscopy (EELS).

Reviewer 2:
The reviewer indicated that the team is on track with milestones. The understanding of what F does to the local structure is useful for this material to move forward. The combination of the theoretical modeling with the experimental work provided a clear understanding of the phenomenon, according to the reviewer.

Reviewer 3:
The utilization of neutron PDF for short-range order in DRX structures provided useful information. It was a well-planned study with reasonable accomplishments on direct fluorination as an alternative method to increase F content in DRX structures. The direct fluorinated of Li-Ni-Ti-Mo oxide materials provided a coating-like structure on the surface. The reviewer stated that it would be helpful to know the stability of the fluoride shell upon charging-discharging. Despite the low performance on direct fluorination of LMNOF material, the team provided the mitigating process to overcome in the future.

Reviewer 4:
Results show the importance of F content and offer useful new insights. The reviewer did not understand the slide showing how direct fluorination of pre-fluorinated DRX cathodes exhibited poor performance. Unfortunately, the video was muted so the reviewer failed to fully grasp the significance of this result.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
According to the reviewer, collaboration seems to be fully implemented between the University of California at Santa Barbara (UCSB) (for NMR), the University of Tennessee (for fluorination), and PNNL (for EM).

Reviewer 2:
The team has satisfactory collaboration.

Reviewer 3:
The reviewer stated that there is good collaboration.

Reviewer 4:
The PI indicated the collaboration and contributions from other team members is going well; that was clear to the reviewer in following the presentation. However, as the overall DRX project moves across several teams, the development process can be improved by stronger coordination that effectively utilizes and integrates learnings from other 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:
Optimization of alternative synthetic routes, such as sol-gel, molten salts, and co-precipitation routes, were proposed. The exploration of new F precursors is also mentioned by the presenter.

Reviewer 2:
The reviewer stated that this is an extension of the continuing work.

Reviewer 3:
The proposed future work seems relevant.

The reviewer did not fully understand the value of developing alternative synthesis methods to produce DRX cathodes.

Reviewer 4:
While the findings in the direct fluorination on lithiated DRX are not all encouraging, the team proposed two different routes to fluorinate the DRX materials. In the solution-based method, the material can benefit from better mixing at the atomic level, but the fluorination process was still unclear to the reviewer. The solution-based method has the potential to control the morphology. It would be interesting to know if the direct fluorination changes the morphology of DRX or forms the coating on the surface.

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

Reviewer 1:
The novel DRX materials research is well aligned with DOE aims for the new SOA LIB system with a Co-free cathode.

Reviewer 2:
It supports the overall DOE objective as the DRX powders studied by the team contain no Co in their structure.

Reviewer 3:
The work will help with the DOE goal of a sustainable and scalable high-energy cathode.

Reviewer 4:
The project is relevant 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 team provides the unique neutron PDF technique to understand structure order and its relationship with Li transport. The team shows enough resources to complete future plans.

Reviewer 2:
The team has adequate resources.

Reviewer 3:
Resources are sufficient.

Reviewer 4:

The reviewer remarked that the resources may not be sufficient in the future if a scale-up of one of the `productions processes has to be implemented.

Presentation Number: bat405
Presentation Title: Advanced Microscopies of Next-Generation Lithium-Ion Battery Cathode Materials
Principal Investigator: Chongmin Wang (Pacific Northwest National Laboratory)

Presenter

Chongmin Wang, Pacific Northwest National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

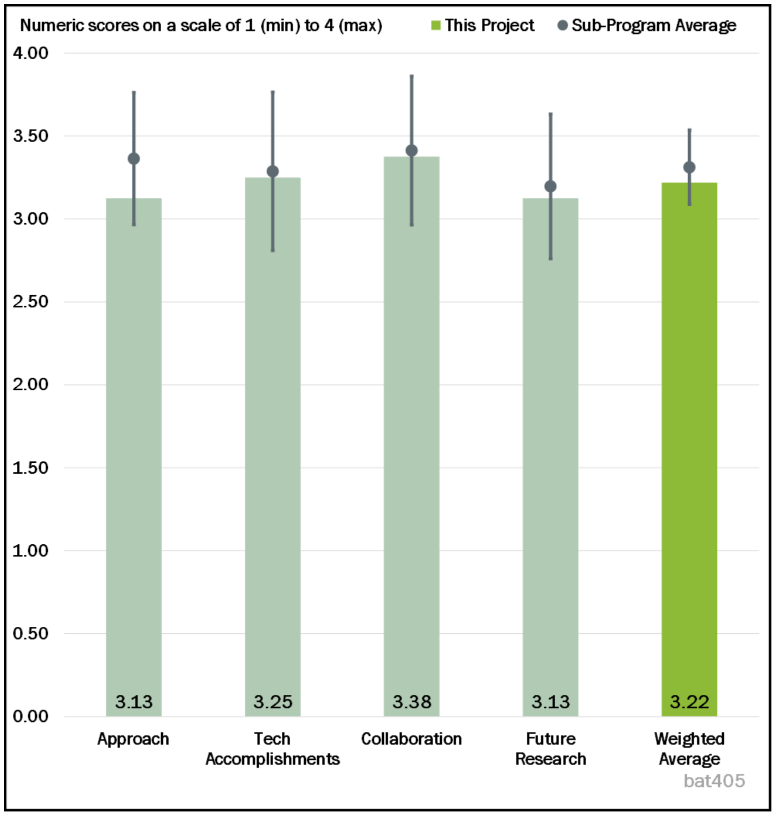

Figure 2-35 - Presentation Number: bat405 Presentation Title: Advanced Microscopies of Next-Generation Lithium-Ion Battery Cathode Materials Principal Investigator: Chongmin Wang (Pacific Northwest National Laboratory)

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 this project disclosed a very interesting finding: by using fast Fourier-transform filtering techniques based on atomic-resolution STEM imaging, the team found ordering patterns (on DRX materials) that can correlate to Li-percolation channels. These characterizations are being integrated with new materials and theoretical work to guide in the design of new cathode materials.

Reviewer 2:

This project focuses on the microscopy studies of the Li-ion cathode materials. The project will help build the fundamental understanding of the modes of cathode failure. EELS and EDS atomic-level techniques are employed.

Reviewer 3:

The reviewer remarked that using advanced microscopy to understand disordered rock cathodes is useful and a relevant approach.

Reviewer 4:

According to the reviewer, the work indicated the overall barrier for material research but did not address how to overcome the current barrier technically.

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 accomplishments are relevant and reasonable within scheduled milestones. The accomplishments started on NMC811 and moved to another two DRX materials (LTMOF and lithium transition metal oxide [LTMO]). Comparing LTMOF and LTMO is a great discovery and shows that long-cycled LTMOF does not have an obvious degraded surface. However, it was unclear to the reviewer about the fluoride part. This would be helpful to show if fluoride encountered any change in the LTMOF material. In the current results, LTMOF also showed O loss. It would be interesting to know if other F-DRX structures still have this transformation or similar structure evolution.

Reviewer 2:
The reviewer found this to be a very interesting approach to study surface reactivity of these cathode material. The in situ TEM observation of surface reactions is showing promising results. The cathode-air interface may be of critical importance during storage of these powders. The reviewer noted that H_2O vapors seem to trigger the chemical delithiation of NMC cathode powders. In a production facility, that could be a critical variable that has to be considered. The investigation of the cation-ordering on DRX materials (that contains no Co) is also extremely important and is being thoroughly investigated by the team. Bulk and surface changes observed on these DRX cathode powders detected by TEM are also great accomplishments presented by the PI.

Reviewer 3:
The images obtained for NMC811 and its various boundaries are interesting. With these atomic surface-level analyses, it was not clear to the reviewer if the full picture in bulk depths is obtained. What if the sample preparation methods alter the surface and give misleading information?

Reviewer 4:
The reviewer said there is good progress to understanding the ordering in DRX.

TEM data showing that cathode-air interfacial reaction depends on Ni concentration are an interesting insight. The reviewer was not sure what the main implication is.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer found the team and its collaboration to be excellent.

Reviewer 2:
Collaboration between the different teams seems to be great. Interactions between LBNL, ANL, ORNL, Hummingbird Scientific, Thermo Fisher Scientific, and the Battery Research group at PNNL seemed to be well coordinated to the reviewer.

Reviewer 3:
There was good collaboration. The group should complement their experimental work with molecular modeling to get a deeper understanding.

Reviewer 4:
The overall DRX projects involved several National Laboratories and academic institutions. The PNNL team established the advanced microscopy approach to reveal the structural and chemical evolution. While the DRX materials involved a wide range of elemental combinations and most of the materials are still under development, the reviewer suggested that the project would be more comprehensive if it indicated the material resources and coordinated with other findings.

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:
For general low-Co and Co-free materials, the reviewer stated that the PNNL team proposes a clear future approach. As DRX material was proposed to have higher stability and less O loss, it would be good to apply the PNNL techniques to other DRX materials and unveil F impact on the DRX. The other teams' presentations indicated that the selection of electrolytes could be a factor affecting the cycled DRX structure, which could be another approach to include in the future plan.

Reviewer 2:
The reviewer noted that the study related to the nature of the ordering in these DRX powders (short-range order) seems to be of critical importance. The atomic-level investigation by using in situ and environmental TEM (ETEM) techniques should increase the level of understanding.

Reviewer 3:
This is an extension of the current work.

Reviewer 4:
Proposed future effort is adequate.

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

Reviewer 1:
Low-Co and Co-free cathode materials are current interests in the DOE-VTO plan. The project is highly relevant to the DOE goal.

Reviewer 2:
This project supports the overall DOE objectives as the DRX powders under study contained no Co.

Reviewer 3:
The results will help the understanding of the fate of cathode material for its rational design.

Reviewer 4:
The project supports 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 team presents the ex situ and in situ TEM and related microscopy techniques to study low-Co and Co-free cathode materials. The reviewer stated that the resources are adequate for the scope of the project.

Reviewer 2:
The team has access to a SOA microscopy facility.

Reviewer 3:
Resources are sufficient.

Reviewer 4:
The reviewer asserted that the project may need additional support if the production process for the DRX materials requires scale up.

Presentation Number: bat406
Presentation Title: Disordered Rocksalt Transition-Metal Oxides (TMOs): Synthetic Strategies
Principal Investigator: Guoying Chen (Lawrence Berkeley National Laboratory)

Presenter

Guoying Chen, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

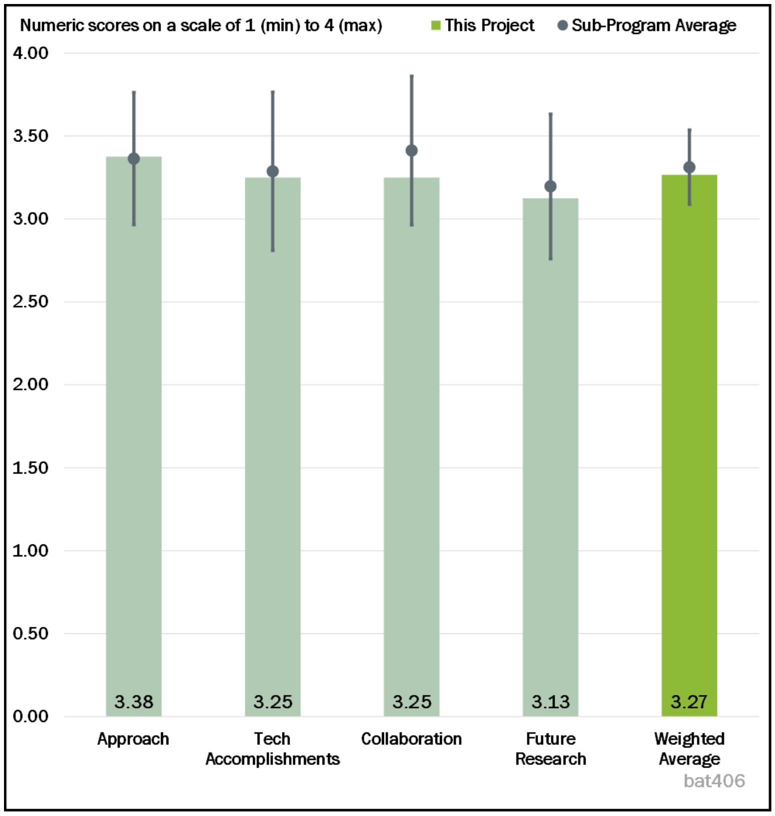

Figure 2-36 - Presentation Number: bat406 Presentation Title: Disordered Rocksalt Transition-Metal Oxides (TMOs): Synthetic Strategies Principal Investigator: Guoying Chen (Lawrence Berkeley National Laboratory)

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 approach seemed to the reviewer to be well designed. The team has focused on DRX materials that contains F. Since F improves many important electrochemical variables in these powders, the team is exploring synthesis conditions to improve this type of cathode materials to increase F content. Powders are electrochemically tested and analyzed to get a mechanistic understanding at the atomic level.

Reviewer 2:

Focusing on synthesis conditions to prepare DRX materials with optimized performance is a promising approach to advance this interesting new material.

Reviewer 3:

The team successfully obtained two out of three proposed DRX materials. Research and development (R&D) and scientific material studies are well designed from fundamental structure to bulk properties. DRX is a new class of cathode materials. The reviewer commented that the current presentation did not always clearly address the technical barriers and approach, specifically the area that the team contributes to while the overall DRX project evolves.

Reviewer 4:

This project focuses on the DRX materials with its synthesis strategies and characterization. The material does provide an alternative to the Co-containing NMC cathode. However, for the new elements, the reviewer asserted that the PI needs to make sure that they are sustainable (e.g., Nb supply 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:
The reviewer observed well-addressed accomplishments on exploring the new materials with synthesis approach and basic material and electrochemical properties for LMNOF and LMTOF.

LMNOF materials gained more attention on material-wide studies including determining voltage-cycling stability, discovering the low conductivity, and determining the F solubility in the current synthesis approach. The reviewer stated that it is a reasonable approach to modify the milestone to determine the F impact on the structure and electrochemical performance. The product from different F contents resulted in different morphology and size. The reviewer said that it would be interesting to know if morphology would be a factor impacting material and electrochemical properties, such as surface properties, packing density, or long-term stability. Also, as the team mentioned, the electrolyte could be a factor to optimize the performance and surface characteristics on DRX materials; this could be a future study or collaboration with an electrolyte expert group in the future.

Reviewer 2:
The reviewer mentioned that the results with the fluorinated cathode powders are very interesting. The team found a variety of positive electrochemical results when working with fluorinated DRX cathode powders. Among the many improvements observed with the fluorinated powders are that the capacity fade is less severe, and stability is increased at higher voltage cycling with fewer severe surface and bulk chemical changes.

Reviewer 3:
The team is making good progress on its milestones. Adjustment was made to expand on the F-content issues. The reported chemo-mechanic behavior and single-particle tomography were interesting to the reviewer.

Reviewer 4:
There is good progress to understanding how high-voltage cycling reduces stability and how carbon additives improve conductivity. The improvement strategy focusing on high F and low Li-TM ratio seemed promising to the reviewer.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This is a well-coordinated project. It seems there is a very good interaction between LBNL, ORNL, PNNL, and UCSB.

Reviewer 2:
The reviewer said that this is a high-quality team and has good collaboration.

Reviewer 3:
The team has members with the required skills.

Reviewer 4:
This DRX project involved several National Laboratories and universities, but the contribution and communication from other project teams were unclear to the reviewer. The project would be clearer if it showed more details on the collaboration between teams. While there is lack of details on coordination from other partners across the project teams, the team has shown the capability to execute the project. It would be great to know if the synthesis approach is optimized based on the feedback from other 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:
Further studies to get a better insight on cycling stability at higher voltages are very important, and the team planned to focus on that area. Increasing the electronic conductivity of these materials is also of great importance.

Reviewer 2:
The proposed future research is well planned.

Reviewer 3:
The reviewer said that this is an extension of the present work.

Reviewer 4:
The project's proposed future research is effective. The reviewer noticed that the TNTMOF materials have not been discussed this year. It would be helpful to know if this material will be included in the future plan.

One of the milestones shifted to optimize the F content and investigate electrochemical capability. Although it is interesting to see the F-DRX study, the reviewer indicated that it would be good to know if the team will consider it in the future. If the production of DRX materials can scale up gradually as in the original plans, it would be useful to study in the larger scale of battery testing and studies.

In the synthesis area, the synthesis approach mainly uses the solid-state method to obtain the DRX structure. Would the team consider the solution method in the future? The solution-based synthesis approach could be easier to scale up in the future.

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

Reviewer 1:
This project is very relevant for the overall DOE objectives since these powders—with no Co content—show great electrochemical potential in terms of electrochemical capacity.

Reviewer 2:
The reviewer said that the study of DRX materials is well aligned with the DOE target for the development of novel cathode materials.

Reviewer 3:
The work is relevant to achieving the DOE targets.

Reviewer 4:
The project is relevant 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 team shows the ability to achieve high-quality results within the timeline and with cross-team collaboration.

Reviewer 2:
The team has access to needed resources.

Reviewer 3:
Resources are sufficient.

Reviewer 4:
The reviewer stated that resources seems to be sufficient; however, the team may need additional support if the project moves toward scale- up of a process to produce larger amounts of cathode powders.

Presentation Number: bat411
Presentation Title: Aerosol Manufacturing Technology for Production of Low-Cobalt Lithium-Ion Battery Cathodes
Principal Investigator: Toivo Kodas (Cabot Corporation)

Presenter

Peter Aurora, Cabot Corporation

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

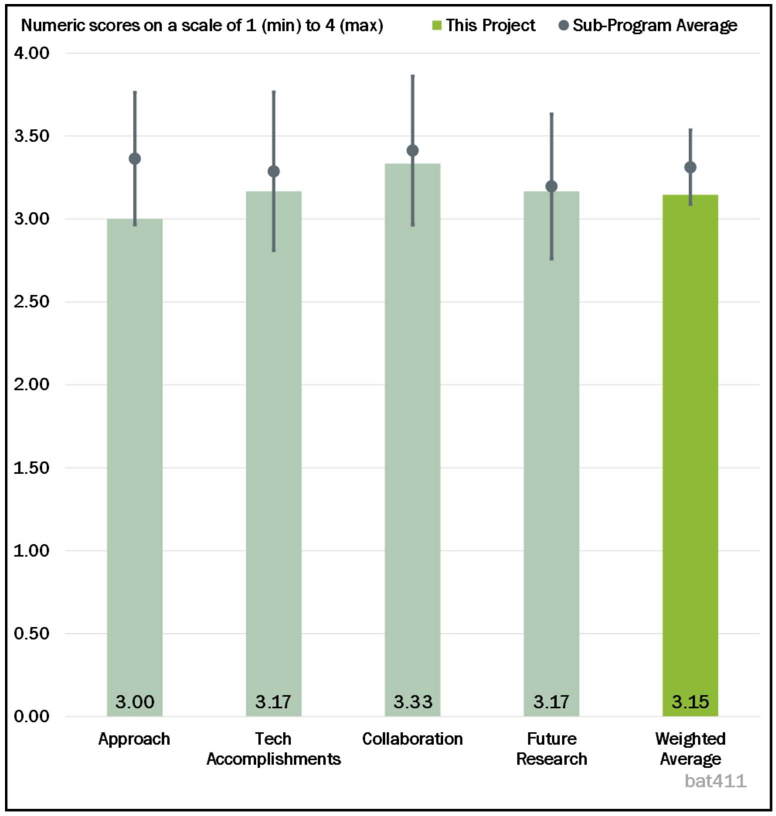

Figure 2-37 - Presentation Number: bat411 Presentation Title: Aerosol Manufacturing Technology for Production of Low-Cobalt Lithium-Ion Battery Cathodes Principal Investigator: Toivo Kodas (Cabot Corporation)

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 a viable, alternative approach to cathode-material production appeared to be a worthy goal, and this project addresses that issue in an effective way. The reviewer's only criticism is that the project would benefit from more benchmarking. While the material is well characterized from a physical and performance point of view, there is no direct comparison to a commercial standard. This is at least possible in the NMC811 system that is used as an example of the production capability. In the same way, there is no legitimate discussion of cost projections from this project although cost targets are prominent in the goals.

Reviewer 2:

The overall performance of reactive-spray technology (RST) for making high-Ni NCM is good. However, the poor particle distribution could lead to variable cell performance and faster fade. From the SEM images, it looked to the reviewer like small particles, which would lead to higher surface area and more CEI formation. This ultimately needs to be addressed before commercialization.

Also, it would be good to see a cost breakdown of the RST–flame-spray pyrolysis (FSP) processes versus the conventional co-precipitation method. It was hard for the reviewer to understand the relevance of trying to introduce a new technology for making materials.

Reviewer 3:

Manufacturing processes and conditions are important in the production of the cathode materials. The presented information has no data on how the proposed RST and FSP methods can reduce the cost of cathode manufacturing. In fact, the reviewer asserted that the annealing temperature of 750°C is in the same range as for the cathodes manufactured using solid-state technology. In addition, the proposed methods include extra steps and some result in waste-stream generation. What is the environmental impact of these technologies?

The reviewer observed that it is important to compare the results to the commercially used materials. For example, what will be the impact of small pore-size distribution (PSD) on safety and stability? The industry is evaluating the possibility of using single-crystal cathodes for this reason.

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:
As stated earlier, while the reviewer would like to have seen more benchmarking, the tasks as proposed were completed in a highly competent manner and the technical work displayed was high quality and comprehensive.

Reviewer 2:
The team has made a number of samples of different compositions. The reviewer commented that it will be interesting to see more systematic studies toward optimization of the physical properties to demonstrate the benefits of the selected techniques. Once again, there is a need to run benchmarking tests to demonstrate advantages.

Reviewer 3:
Performance of the RST-FSP methods for high-Ni cathode active materials (CAMs) is decent. However, significantly more work is needed to improve the PSD. This is likely needed before the commercialization of the cathode material.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer found the team collaboration to be strong. It is sending the CAM materials to Saft where the company is building the pouch cells and doing the necessary testing.

Reviewer 2:
The team is definitely well aligned.

Reviewer 3:
Collaboration appears appropriate for the stage of the project. Collaboration will need to increase in scope as the project matures.

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:
Most of the future goals are appropriate. The reviewer had some question about the ability of the participants to effectively address the goal of optimizing the actual cathode-coating procedure, however. This could possibly benefit from a more suitably qualified partner.

Reviewer 2:
The proposed plan is to scale up the RST method. However, the reviewer thought the challenge remains in the method of creating the small particle size. The reviewer suggested going back and revisiting how to get better particle uniformity before focusing on scale-up.

Reviewer 3:
The future work is focused on optimization of the synthesis conditions, cell testing, coating, etc., which is a standard route for any new development. The team must focus on answering question regarding the cost, including waste-stream recycling.

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

Reviewer 1:
The synthesis of high-Ni $Li_{1+w}[Ni_xCo_yMn_z]_{1-w}O_2$ (NCM) is important, and methods to reduce the cost and boost cell performance are needed. This project aims to address those issues.

Reviewer 2:
The development of newer variations of experimental low-Co structures requires a capability to produce at reasonable levels. Even if this project does not become cost viable at a large commercial level, it may very well be the bridge process required to produce reasonable scale-up volumes of experimental material.

Reviewer 3:
Cost reduction is extremely important for the industry growth. However, it was not clear to the reviewer how this project could achieve the objective.

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 team has sufficient resources to complete the project along with know-how from the National Laboratory and testing from Saft.

Reviewer 2:
Resources appear sufficient for the time being. Broader participation with other collaborators in the future should be anticipated.

Reviewer 3:
Technical resources are sufficient. The reviewer commented that the team might need to add the cost estimator.

Presentation Number: bat412
Presentation Title: Novel Lithium-Iron and Aluminum Nickelate (NFA) as Advanced Cobalt-Free Cathode Materials
Principal Investigator: Ilias Belharouak (Oak Ridge National Laboratory)

Presenter

Ilias Belharouak, Oak Ridge National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

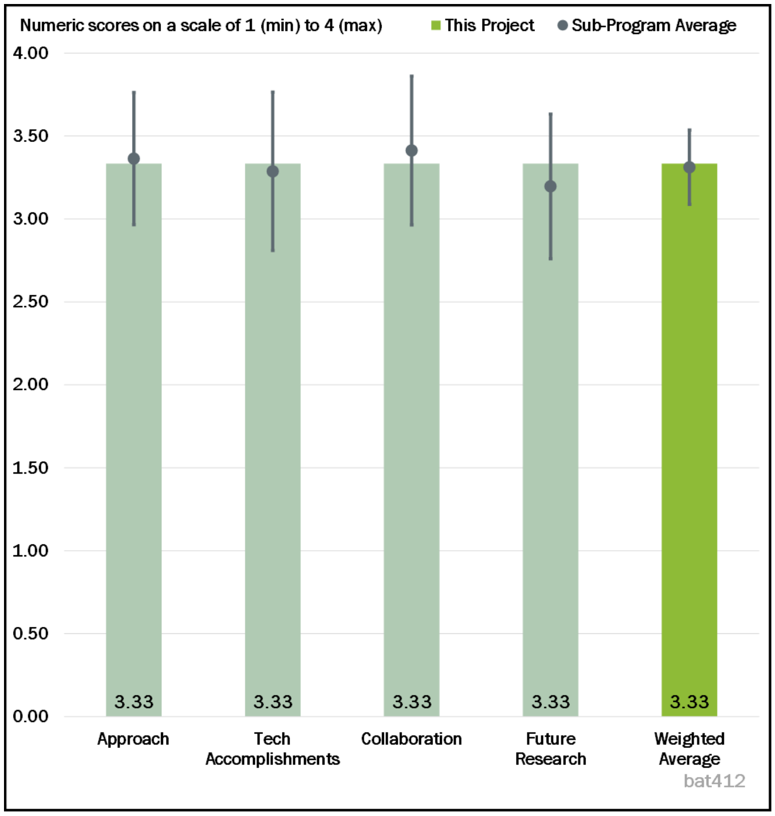

Figure 2-38 - Presentation Number: bat412 Presentation Title: Novel Lithium-Iron and Aluminum Nickelate (NFA) as Advanced Cobalt-Free Cathode Materials Principal Investigator: Ilias Belharouak (Oak Ridge National Laboratory)

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 approach the team has taken to making a Co-free nickelate material has been great. The team has addressed technical barriers and overcome them. The one question from the reviewer is if the team is going to improve the electrode loading, percent active in formulation, and porosity during the electrode development.

Reviewer 2:

The work takes on the interesting task of developing and evaluating the potential of a nanostructured ferritic alloy (NFA)-based, metal-oxide cathode system. This is done in a generally credible way, the reviewer said, and that synthesis aspect of the work appears more accomplished than the performance-evaluation part of the work. To be fair, this is not a high-dollar project and comprehensive evaluation is a very costly endeavor. As with other projects in this subset, there is little benchmarking available at this stage of the work.

Reviewer 3:

Overall, this is a very well managed research project. The reviewer was curious about why Fe was used as a substitute. The amount seems to be very low and since there is no benchmarking versus commercially available materials with the same Ni+Co content, the claim that Fe improves rate capability is not supported. Provided industry “scare” of any Fe in the material, it will be interesting to know the OEM feedback. There have been many publications for the $LiNiO_2$ with Al, Mg, Ti, etc., doping. Why Fe? Is it the mentioned high sensitivity to moisture due to Ni, not Fe? Or both? Why the volumetric energy density is low? Is it due to the synthesis route?

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 very solid, high-quality experimental work. It will be useful to add benchmarking versus industrially produced samples of similar composition.

Reviewer 2:
The team has successfully synthesized phase-pure nickelate and used advanced characterization to understand the material. The electrochemical performance was great for preliminary work. The team has also shown the ability to use a scale-up process to make kilogram-level quantities of the material with electrochemical performance comparable to a small batch. Lastly, the reviewer stated that the team has shown a technical approach to fabricating large-format cells for testing.

Reviewer 3:
The production and characterization of the material targets appears to be on track and competently done. Performance characterization needs more work, but the reviewer noted that this is also not scheduled to be completed at this time.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer asserted that there was great use of the National Laboratories and industry resources.

Reviewer 2:
The ream has used collaborations to its advantage, and it shows with the quality of work and the transfer to larger scale pouch cells.

Reviewer 3:
There was no work product from either Xalt or Nissan displayed in the presentation. It was not clear to the reviewer from the presentation when their contribution will be required and what specific tasks they will be performing.

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 team has a good, proposed future-research plan and should be able to hit its targets.

Reviewer 2:
The Gen-2 NFA development culminates in a cell build and characterization effort. In order for the material to get a fair evaluation for future promise, a fair bit of planning needs to go into the structure of that evaluation.

Reviewer 3:
The reviewer suggested that benchmarking versus commercial materials tested in the same cell design should be added.

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

Reviewer 1:
This project is very relevant as a Co-free cathode with higher energy density.

Reviewer 2:
The reviewer said that this is an intriguing alternative to NCA-style cathode chemistry and deserves a robust evaluation for its potential effectiveness.

Reviewer 3:
There are not enough data for the reviewer to understand the motivation for the use of Fe.

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.

Reviewer 2:
There are well coordinated and utilized resources.

Reviewer 3:
The reviewer said that resources are sufficient for now; evaluation resource sufficiency will be more on display next year.

Presentation Number: bat413
Presentation Title: High-Performance, Low-Cobalt Cathode Materials for Lithium-Ion Batteries
Principal Investigator: Donghai Wang (Penn State University)

Presenter

Donghai Wang, Penn State University

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

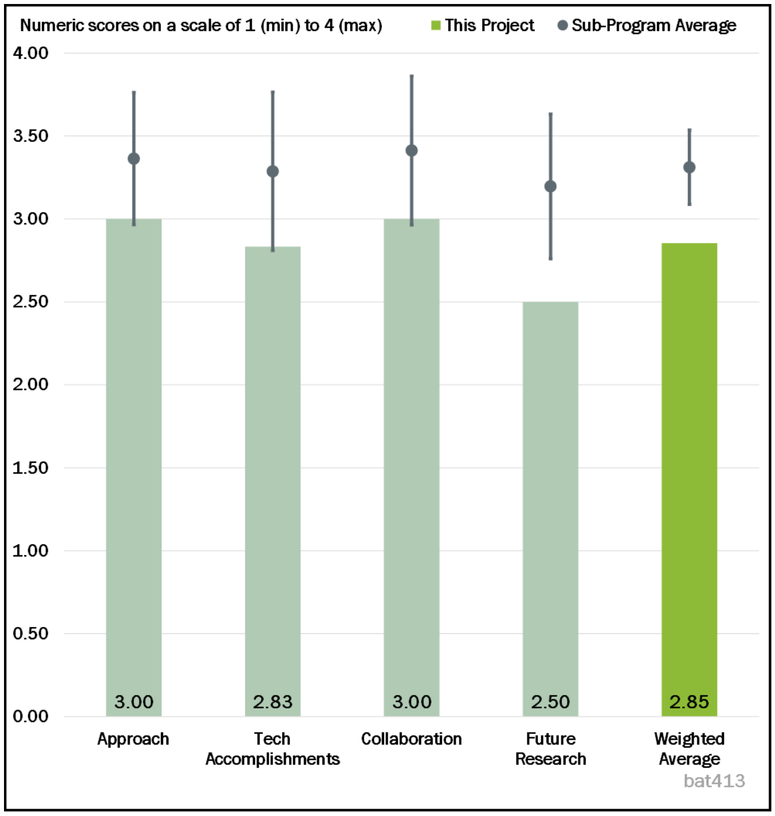

Figure 2-39 - Presentation Number: bat413 Presentation Title: High-Performance, Low-Cobalt Cathode Materials for Lithium-Ion Batteries Principal Investigator: Donghai Wang (Penn State University)

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 viewed the approach of producing high-Ni NCM with low-Co content through coatings and doping as solid.

Reviewer 2:

There is a mix of approaches being tested here, with varying issues associated with each one. There is some good output related to technique development in materials analysis at the atomic level, which may be the more compelling output of the program to date.

Reviewer 3:

Industry has been using low-Co, high-Ni materials for some time. The team has focused on making a number of pretty standard compositions and, hopefully, it can spend more time on establishing structure and performance relationships and use advanced characterization tools to establish new material-development principles. Since the team is having difficulties in making high-quality materials, the reviewer suggested that it might consider partnering with the teams that have high-quality samples and use them for investigations and theories development.

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's coated aluminum oxide (Al_2O_3)-NCM performance is not good. It does not make sense that the capacity drops so much with the DC-NCM-Al_2O_3. Also, the reviewer stated that the bare NCM material is really poor, so it is a bad comparison.

Reviewer 2:
The objective of this project is to develop stabilized NCM cathode materials with low-Co content. The work done to date shows a few interesting ideas; however, it seemed to the reviewer that the team has spent most of its time on making samples versus doing a deep drive into atomic- and electronic-level correlation of the structure and chemistry.

Reviewer 3:
The reviewer found no consistent theme within the work but rather a mix of different approaches based on different material sets and development activities.

The first approach is the attempt to apply coatings as a stabilizing material for metal-oxide cathode materials. Lithium-iron phosphate (LFP) is applied to NMC811 to some positive effect. Unfortunately, NMC811 is not an acceptable candidate within the goals of the low-Co program, and the LFP coating technology is not applied to any other material. An Al_2O_3 coating is applied to a low-Co (Co=0.055) NMC material. Al_2O_3 is a common coating technology in the industry these days and is well known to provide some benefit and is widely available in commercial materials. The NMC material chosen has very poor cycle life, which is not helped by the Al_2O_3 application in this case (at least in the sense of an 80% cycle-life cutoff value)

Next, a LNMM0 material is synthesized and tested with no coatings. Cycle life is very poor, and much work would need to be done to improve it.

Finally, a NM91 material is synthesized and cycle life is essentially non-existent.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
It seemed to the reviewer like the collaborations have been used appropriately. Perhaps more input on the quality of the non-coated NCM could have been discussed further.

Reviewer 2:
The characterization performed by PNNL seems like a good contribution to the field. The split of work between Penn State and ORNL was not completely clear to the reviewer although at some point the presenter suggested that ORNL did the Mo-doped material.

Reviewer 3:
The team might consider adding a partner to accelerate sample preparation so they can have more time on characterization.

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 work for the remainder for FY 2020 and for FY 2021 seemed adequate to the reviewer.

Reviewer 2:
The proposed research is mainly focused on producing pretty standard composition samples.

Reviewer 3:
The serious deficiency of cycle-life capability for many of the materials needs to be addressed at a more fundamental level before further work should be considered.

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

Reviewer 1:
The project is very relevant in terms of reducing the Co content in NCM cathode materials as well as providing surface coatings to help stabilize the NCM high-Ni structure from electrolyte decomposition.

Reviewer 2:
These are legitimate materials developments to apply to low-Co. It could benefit from a more coherent approach.

Reviewer 3:
The objectives are relevant, but the reviewer was not clear if the team can meet them.

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

Reviewer 1:
The team has sufficient resources.

Reviewer 2:
No comment was indicated by this reviewer.

Reviewer 3:
The reviewer said that the project might need help with sample delivery for studies.

Presentation Number: bat414
Presentation Title: Enhancing Oxygen Stability in Low-Cobalt, Layered-Oxide Cathode Materials
Principal Investigator: Huolin Xin (University of California at Irvine)

Presenter

Huolin Xin, University of California at Irvine

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

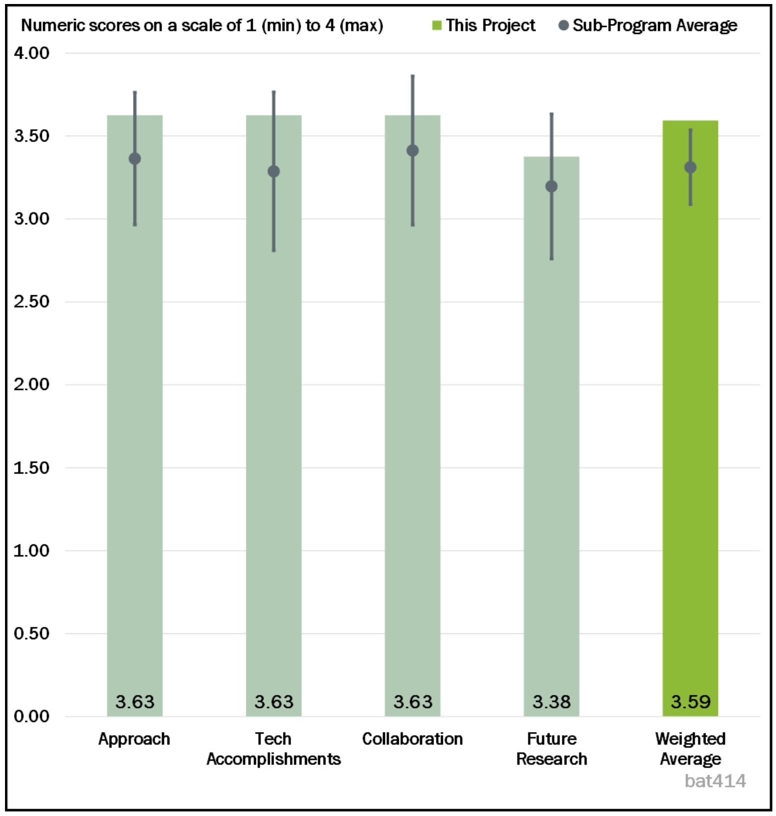

Figure 2-40 - Presentation Number: bat414 Presentation Title: Enhancing Oxygen Stability in Low-Cobalt, Layered-Oxide Cathode Materials Principal Investigator: Huolin Xin (University of California at Irvine)

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 is systematic, and the strategy covers the path to test several hypotheses to meet the project objectives. According to the reviewer, there is an excellent balance of theoretical and laboratory work. There is excellent marketing: the work on surface and bulk doping of $LiNiO_2$ with Ti and Mg had been published in 1998 but using the term 3-D doping technology should re-invigorate the interest and use by industry, provided that IP will expire this year. This reviewer also recommended *Electrochemical and Solid-State Letters* 1 (3) 117-119 (1998): Novel $LiNiTiMgO_2$ Compounds as Cathode Materials for Safer Lithium-Ion Batteries.

Reviewer 2:

The approach is great to investigate lowering the Co amount in high-Ni NCM materials through surface and bulk doping. The team also utilizes modeling to understand the role of the improvements of dopants.

Reviewer 3:

The PI proposed highly effective approaches to address the barriers. In addition to novel electrolytes and cathode doping, the PI also proposed high-throughput computation to guide materials design. The PI recognized the critical issue of O loss in high-Ni NMC and proposed techniques to characterize and mitigate O loss.

Reviewer 4:

The work is intending to apply a scientific approach to doping high-Ni metal-oxide cathode materials in order to replace the function of the Co. The reviewer reported that the project has a good blend of experimental and theoretical approaches that should help better understand the concept and potential efficacy. There is some interesting electrolyte interaction work that is also applied although there is less analysis applied to the fundamental mechanistic improvements that the electrode-electrolyte interface is exhibiting.

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 there was impressive computational work for dopants selection and an excellent demonstration of the electrolyte formulations on SEI-CEI stability.

Reviewer 2:
The project's technical accomplishments are great. The team has doped NMC811 and used advanced analytical characterization to understand the role of the dopant as well as using computational modeling. From that, the team has been able to do co-doping to further improve performance. Additionally, the team has found electrolytes that will work with the team's full-cell system that show superior performance to the baseline.

It would be good, however, to show the stability in various storage applications for the NMC material. High-Ni NCM tends not to be stable when stored in humidity or air for long periods of time. It would be interesting to the reviewer to see how the material performs with storage testing, as well as looking at the amount of residual lithium hydroxide and lithium carbonate on the surface as a function of storage time and relative humidity. It would be interesting to see if the surface coatings help with this.

Reviewer 3:
Based on modeling guidance, the team synthesized surface and bulk-doped, Co-free nickelates and demonstrated good cycle life in the doped nickelates. The team also demonstrated the effectiveness of an LHCE in reducing the cycle-life fade of Co-free nickelates.

Reviewer 4:
The impact of the doping on basic performance and the fundamental analysis elucidating some aspects of the mechanism from a materials point of view is fairly strong. There is good analysis followed by relevant conclusions.

Again, the electrolyte interaction work was interesting, but with a less fundamental mechanistic conclusion.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The team has used its collaborations to its advantage. The work done is great and seems that all parts are working together.

Reviewer 2:
The PI assembled an excellent team, with clear description of the role of each team member.

Reviewer 3:
The reviewer commented that there is outstanding use of the talent, characterization tools, and theory within the National Laboratory network.

Reviewer 4:
There is good interaction between synthesis, modeling, analytical analysis and interpretation—good job.

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 team discussed the remaining challenges of thermal stability and scale-up and should also consider storage life of the NCM powder. Otherwise, the proposed future research plan is good.

Reviewer 2:
The path forward is clear, and the choice of NMC622 for benchmarking is a good target.

Reviewer 3:
Hopefully, the scale-up work to 100-g level is sufficient to support the next level of characterization. The reviewer asked if that level may be a little light.

Reviewer 4:
Even though the project is only 40% completed, the reviewer commented that great progress was made in demonstrating the feasibility of Co-free nickelates. Due to the high 4.4 V cut-off, in addition to cycle life, the team needs to demonstrate progress toward achieving the stated 15-year calendar-life goal in fully charged cells. The team should also demonstrate performance using cathode loadings of 3-4 mAh/cm^2 in order to meet the energy-density targets.

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

Reviewer 1:
The work will provide a knowledge base for selection of the dopants and further emphasize the role of the electrolyte formulation.

Reviewer 2:
The work on lowering the Co amount and having high-energy cathode materials is relevant, according to the reviewer.

Reviewer 3:
In the realm of stabilizing high-Ni materials without the use of Co, this is an obviously a good set of approaches to develop options based on understanding.

Reviewer 4:
The project is very relevant for a program on low-Co cathodes. The PI should elaborate on the uniqueness of the doped nickelates by taking into consideration the Co-free nickelates effort published by Dahn's group—*JES* 166(4), A429 (2019). While the PI demonstrated feasibility of $LiNiO_2$ doped with Mg and Mn, the absence of Mn in Dahn's $LiNi_{0.95}Mg_{0.05}O_2$ might reduce the TM- dissolution issue.

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

Reviewer 1:
The right talent and tools are in place.

Reviewer 2:
All the proper bases appear covered.

Reviewer 3:
The reviewer said that the team has sufficient resources to solve its challenges.

Reviewer 4:
The project has sufficient resources.

Presentation Number: bat415
Presentation Title: High-Nickel Cathode Materials for High-Energy, Long-Life, Low-Cost Lithium-Ion Batteries
Principal Investigator: Arumugam Manthiram (University of Texas at Austin)

Presenter

Arumugam Manthiram, University of Texas at Austin

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

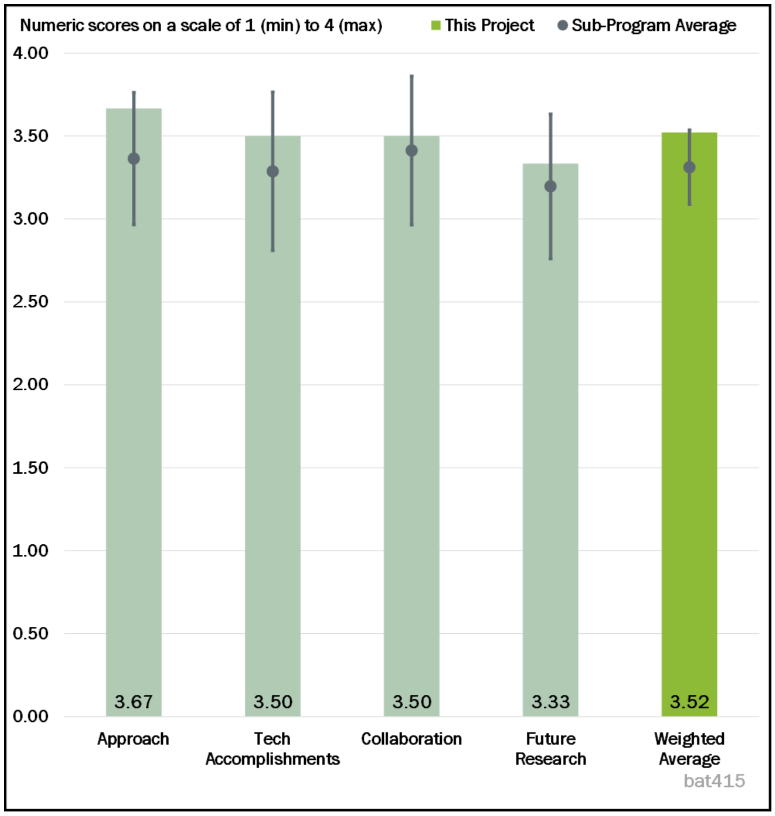

Figure 2-41 - Presentation Number: bat415 Presentation Title: High-Nickel Cathode Materials for High-Energy, Long-Life, Low-Cost Lithium-Ion Batteries Principal Investigator: Arumugam Manthiram (University of Texas at Austin)

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 work on low Co and the approach presented by this group is great. It has a focused goal to investigate the compositions and scale-up of the material.

Reviewer 2:
The reviewer found this to be a very well designed and executed experimental plan. The team might benefit from the work conducted under BAT414 in regard to the guidance and strategy for the selection of the dopants using the modeling tools. There is excellent work for the technology assessment using commercially relevant requirements.

Reviewer 3:
This work explores the familiar theme of minimizing Co in Ni-based cathode materials by trying to substitute other stabilizing structural and dopant components. It contains good experimental and analytical evaluation.

Interaction with collaborators does not seem very coordinated, and the reviewer asserted that some attention should be paid to following up on the good results that are currently being generated.

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 technical accomplishments are excellent, and they show the need for an O_2 atmosphere for annealing these high-Ni systems. According to the reviewer, the doping also shows improvements over the pure $LiNiO_2$. The team was also able to show high cycling stability with 2 Ah pouch cells.

Reviewer 2:
Very high-quality work and steady process were observed by this reviewer.

Reviewer 3:
Several base-material combinations have been tested and evaluated. The nickel manganese aluminum (NMA) material exhibited good behavior versus some reasonably well-known standard materials. The effect of calcination pressure was also an intriguing study that seemed to show a strong response.

The initial doping studies are interesting; however, with a comparison only to the control—pure NiO_2 material—it is a little difficult to assess just how the doped materials compare to known standard material sets.

Work performed by partner NREL provided a LiNiCoMnAlMg material to Tesla for evaluation. It was not clear to the reviewer why this material was chosen or how it fits into the overall program.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer called this a great team and gave kudos for having an OEM on board to provide assessment and feedback.

Reviewer 2:
The team displays a great use of collaboration.

Reviewer 3:
The collaboration between UT-Austin and NREL does not seem to be particularly well coordinated. The roles and synergies between the two organizations was not very evident to the reviewer from this 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 team's approach to attempting higher electrode loading and studying the calendar effects are industry relevant and important for the success of this material.

Reviewer 2:
The stated goal for the future is a survey of LiNiCoM material with dopants as well as ALD coatings, followed by evaluation of Co-free versions of the same. The reviewer was not sure why the Co-containing versions are receiving attention, given the work already done in the NMA Co-free version. Hopefully, the work on Mg-Cu doping that was performed will also be followed up on.

Reviewer 3:
The team might consider reviewing the models developed within the DOE program (for example, BAT414) to guide selection of the dopants; the reviewer opined that this might accelerate discovery and objectives delivery.

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

Reviewer 1:
This project is very relevant for removing Co from cathodes while having high capacity and cycling performance.

Reviewer 2:
This team is one of the most knowledgeable in the high-Ni research field and has the most experienced partner to do evaluation and testing.

Reviewer 3:
Stabilization of NiO_2 -based cathode materials with materials other than Co, as well as dopant and coating approaches, is the most likely path toward a Co-free, high-energy cathode system.

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

Reviewer 1:
The team has displayed that it has enough resources for the success of this project.

Reviewer 2:
The reviewer had no issues.

Reviewer 3:
Using recent modeling developments within the DOE program might accelerate this team reaching their milestones for the survey of the compositions and dopants.

Presentation Number: bat416
Presentation Title: Cobalt-Free Cathode Materials and Their Novel Architectures
Principal Investigator: Shirley Meng (University of California at San Diego)

Presenter

Shirley Meng, University of California at San Diego

Reviewer Sample Size

A total of # reviewers evaluated this project.

Project Relevance and Resources

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

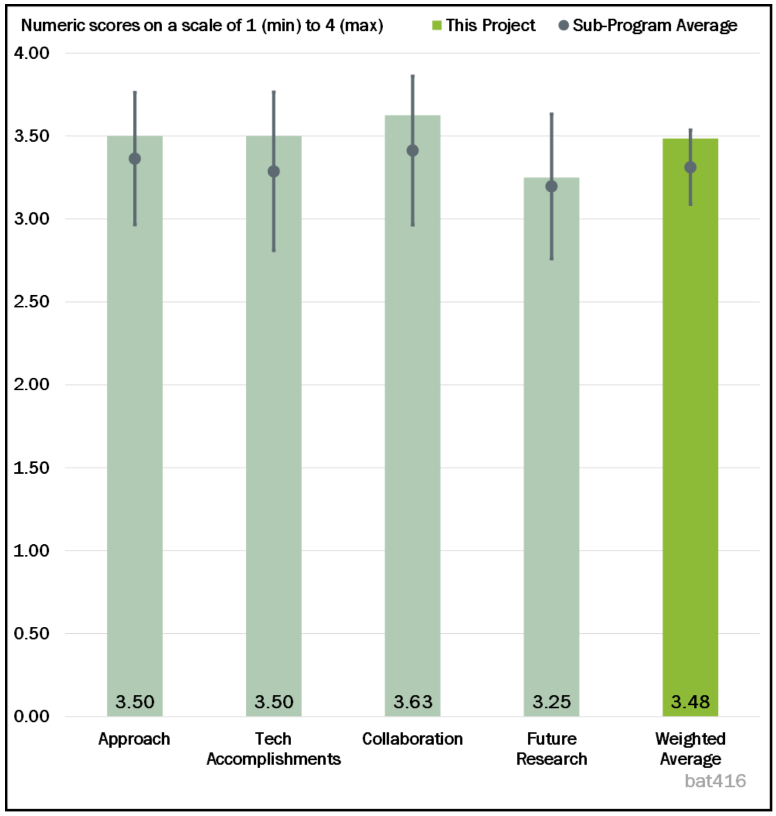

Figure 2-42 - Presentation Number: bat416 Presentation Title: Cobalt-Free Cathode Materials and Their Novel Architectures Principal Investigator: Shirley Meng (University of California at San Diego)

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 this was a very thoughtful and practical approach to mitigate the limitations preventing use of the LMNO chemistry. The attention to details and the development of the new characterization techniques are commendable. The reviewer was curious about what the partners think about the high-voltage requirement to reach energy-density targets and what the plans are to solve performance issues at elevated temperatures. It will also be interesting to see if the dry-electrode method will work for other cathode chemistries.

Reviewer 2:

The reviewer indicated that the approach of Co-free $LiNi_{0.5}Mn_{0.5}O_2$ (LNMO) with thick electrodes is great. The team has the necessary experience and has addressed the technical barriers. The project is well designed and feasible.

Reviewer 3:

The approach in this effort is through the use of reasonably well known LNMO material but with a high tap density and thick electrode structure to make up for the inherent lower capacity of the LNMO material. This is probably worth exploring in order to cover all possibilities in the search for an acceptable low-Co material.

Reviewer 4:

The PI proposed effective approaches to address the barriers. A combination of surface characterization tools was used to understand the electrode-electrolyte interface instabilities. Novel electrolyte additives and cathode doping were proposed to address the high-voltage electrolyte instability, and a dry cathode coating was proposed to fabricate thick 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 remarked that this is high-quality research: attention to details leads to better material and cell designs. The research is on track.

Reviewer 2:
The technical accomplishments are great. The team studied the binder and conductive carbons, which are an important aspect when dealing with high-loading electrodes. Additionally, stack pressure is important as the team shows. The technical challenges that remain are to address the rate performance with these high-loading electrodes.

Reviewer 3:
The reviewer commented that the accomplishments to date mainly center around base-material identification and electrode- and cell-architecture baselines.

Reviewer 4:
The team was successful in increasing the loading and demonstrating cycle-life feasibility with 3 mAh/cm^2 in pouch cells. TM dissolution from the cathode deposited on the anode and Li-inventory loss were identified as major contributors to cycle-life fade.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented that the PI assembled a team of experts, including an industry partner that contributed to the success to date.

Reviewer 2:
There is the right talent on the team to solve the limitations of the LMNO chemistry.

Reviewer 3:
The team has used its collaborations adequately.

Reviewer 4:
Due to the baseline process and design work, there has not been a lot of opportunity to view collaboration dynamics. This will be more relevant in future 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 noted that the team will aim to dry coat the LNMO to make single-layer pouch cells, which is important, as well as study the effect of electrolyte and electrolyte additives.

Reviewer 2:
The project is 50% completed. Building on the success of the first half, the team needs to demonstrate the effectiveness of its approaches in mitigating high-voltage electrolyte instabilities. Due to the ultra-high voltage cathode, in addition to cycle life, the team also needs to demonstrate stable calendar life in fully charged cells. Since stack pressure is critical to good cycle life, the pressure impact should be quantified.

Reviewer 3:
Future research is predominantly focused on characterization of the modified LMNO samples with different electrolytes and electrodes made using dry coating method. It will be beneficial to assess the cost, safety, and performance implication of the high-voltage requirement on the battery-pack design and seek feedback from the OEM partner. In addition, there is a need to focus on the elevated temperature performance.

Reviewer 4:
The specifics of the material-modification approaches for the LNMO material are not well defined in the presentation, according to the reviewer.

Electrolyte studies related to reactions at the electrode-electrolyte interface should be of some interest as this is a higher voltage system that may have complications in this area.

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

Reviewer 1:
The use of the dry-electrode production method is very important from the viewpoint of cost and environmental impact to the industry. The reviewer indicated that the ability to increase areal electrode loading with no detriment to the rate capability is another strength of this project.

Reviewer 2:
LNMO cathodes with high loading are important for industry.

Reviewer 3:
LNMO is a Co-free material with a commercial history in the Li-ion industry. Exploring its limits seems like a reasonable goal for a zero Co-cathode system.

Reviewer 4:
The reviewer stated that the research is relevant for a project on low-Co cathodes. However, a comparison of cost, energy density, and life based on full cells should be made with low-Co or Co-free NMC to justify the risks associated with the ultra-high voltage LNMO spinel.

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

Reviewer 1:
The right balance and good long-term relationships are in place.

Reviewer 2:
The reviewer stated that the team has sufficient resources for this project.

Reviewer 3:
The reviewer had no issues.

Reviewer 4:
Since the electrolyte is a critical enabler for the ultra-high voltage LNMO, some resources should be devoted to electrolyte development.

Presentation Number: bat417
Presentation Title: Cobalt-Free Cathodes for Next-Generation Lithium-Ion Batteries
Principal Investigator: Neil Kidner (Nexceris)

Presenter

Neil Kidner, Nexceris

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

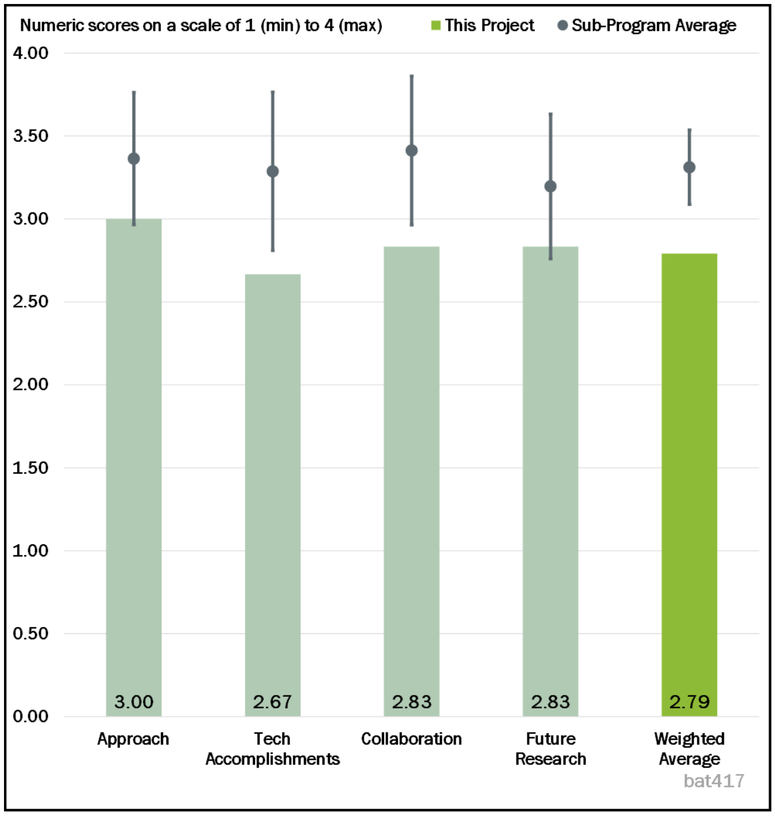

Figure 2-43 - - Presentation Number: bat417 Presentation Title: Cobalt-Free Cathodes for Next-Generation Lithium-Ion Batteries Principal Investigator: Neil Kidner (Nexceris)

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 consists of providing a Ti-rich, core-shell layer on the surface of LNMO cathode material. Integrated shell layers are a well-known approach and the value of this specifically is certainly worth addressing.

Reviewer 2:

The plan is to make LNMTO cathodes with improved cycle and calendar life by forming an SEI through a core-shell approach. While the approach in theory is good, it was unclear to the reviewer if the direction the group is taking is the best. For example, in the coin-cell work, the team used a PVDF binder, but showed lithium polyacrylate (LiPAA) in the full cells. It seemed to the reviewer that PVDF cycles were much better than the LiPAA cycles, so it was unclear why there was a change. The team also does not adequately show why it is using Ti in the LNMTO system. It seems like the team needs to regroup on its approach to better address the technical barriers.

Reviewer 3:

The initial results show that LMNTO cathode capacity is decreased while the cyclability is not improved to meet the project targets. It was interesting to the reviewer to see that LMNO used for comparison fades too rapidly. In the BAT416 presentation, researchers demonstrated more than 300 cycles at 80% capacity retention. Therefore, it is difficult to understand the motivation for continuation of the investigation of this cathode chemistry, which is further complicated with the high-voltage-performance requirement not yet embraced by the OEMs. It was obvious to the reviewer that the co-precipitated syntheses method will result in higher uniformity, but as researchers indicate, it will be difficult to scale up. Researchers might need to review their strategy to ensure project objectives are met.

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 initial results are far from reaching the project objectives on all merits except that the material is Co free.

Reviewer 2:
At one level, the results show that the addition of a shell layer of Ti-rich material provides a marked improvement over the non-coated material. The reviewer's concern with these results is that the performance of the LNMO control material is very poor. The LMNTO material does provide favorable improvement but also poor performance on an absolute basis. There needs to be some concern about the poor performance of the control material before too many conclusions are drawn.

Reviewer 3:
The scale-up from 20 g to 2 kg shows a drop in capacity as well as differences in the voltage profile. It was unclear to the reviewer why that is the case, but it may be due to homogeneity in the synthesized particles. It would be good to have confirmation through inductively coupled plasma that the team is also getting the desired stoichiometry. The work shown in the 2-Ah pouch cell shows improvement but with a really poor baseline. Unfortunately, the group presenting before them showed 3.5-Ah cycling in a pouch cell for LNMO baseline, and that had much better performance. It is also unclear how much a of cost difference there is between the solid-state versus co-precipitation methods shown.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Collaboration seemed appropriate to the reviewer. Synthesis, lab-cell analysis, and larger pouch-cell builds appear to be in place.

Reviewer 2:
Navitas is a very experienced team and might need to be more engaged to provide direction.

Reviewer 3:
It indicated to the reviewer that the team could have used its collaborations better to achieve their project goals: for example, the changing of binders, the scale-up that does not show the same cycling performance, and the 2-Ah cells that do not reach the desired cycle life.

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 suggested that re-evaluating the strategy should be the number 1 priority.

Reviewer 2:
The reviewer asserted that the team should go back and address some of the other issues brought up in terms of electrode formulation (i.e., binder, carbon, and loading) before moving to the proposed future work.

Reviewer 3:
It is stated that a large amount of the performance shortfall of the material is related to the electrolyte-degradation issue in the high-voltage environment. An electrolyte study is prudent; however, this is a challenging task and requires specific expertise that is not necessarily accounted for in the collaboration.

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

Reviewer 1:
LNMO is a well-known chemistry in the field with well-known pros and cons. If there are material developments that could improve upon the system, they would serve the goal of finding high-energy material without a significant Co penalty.

Reviewer 2:
The reviewer stated that the project is relevant research but needs better focus and the ability to hit the targets.

Reviewer 3:
The reviewer asserted that there is a need to have help and/or direction.

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

Reviewer 1:
It seemed to the reviewer that the team has sufficient resources.

Reviewer 2:
Resources are sufficient unless the focus on electrolyte needs to be acted upon within this effort.

Reviewer 3:
The team needs additional collaborations and to re-evaluate its strategy, according to the reviewer.

Presentation Number: bat436
Presentation Title: Silicon Electrolyte Interface Stabilization (SEISTA): Update and Overview
Principal Investigator: Tony Burrell (National Renewable Energy Laboratory)

Presenter

Tony Burrell, National Renewable Energy Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

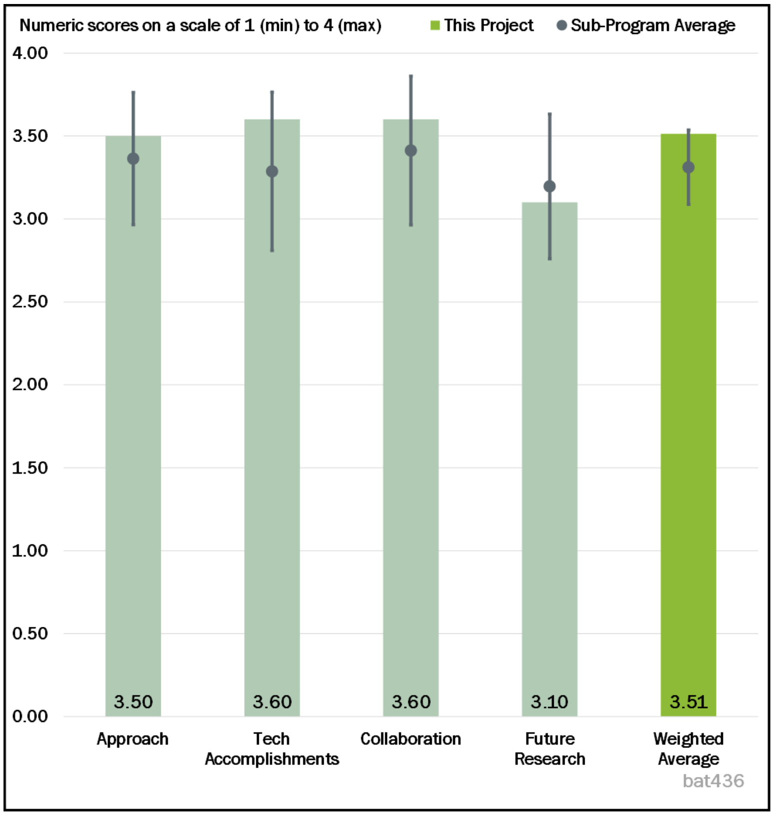

Figure 2-44 - Presentation Number: bat436 Presentation Title: Silicon Electrolyte Interface Stabilization (SEISTA): Update and Overview Principal Investigator: Tony Burrell (National Renewable Energy Laboratory)

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 project is well organized, well designed, and highly focused. It was very evident to the reviewer that a lot of careful thought had gone into planning this project.

Reviewer 2:

The overview to the Silicon Electrolyte Interphase program did a good job of addressing the important technical barriers and does a good job coordinating the large number of researchers working on the project. The goals of the project were clear to the reviewer, and the design of the work groups and the work packages is good. The project has feasible goals that will likely provide benefits to the U.S. automotive industry by laying the groundwork to improve the energy density of anodes for LIBs.

Reviewer 3:

The reviewer listed some comments:

- It is a careful approach.
- Calendar life is called out, but there is no follow-up.
- Looking for alloys that enhance durability is a very important approach.
- Rather than just characterizing everything, a particular Zintl phase is identified as important and useful, so the work focused there.

Reviewer 4:
This project appears to be well designed and has significant communication with adjacent energy-storage programs, including the Deep Dive, in order to ensure that there is not a duplication of work. The presenter mentioned that the team is stage-gating sub-programs with go/no go decisions in order to ensure it is continually focusing on promising projects.

The presenter described a critical step in the validity of this project by standardizing the testing protocols between groups to predict calendar-life testing. This enables much for more reliable testing between laboratories in the consortium.

Reviewer 5:
This was a good overview of a lot of work. However, the reviewer indicated like it did not tie together as well as last year. A strength is that the group is seeking to understand what is critical to fixing the problem, and this is the group that can do it. A weakness is the focus on areas that are not necessarily mainstream to get the understanding.

Is Mg the answer? There is a lot of effort on this, but will the understanding really help? The reviewer sees that the industry is moving toward SiO_x, and asked where that understanding is? The reviewer knew that the team needs to focus narrowly to get understanding, but is the narrow focus aligned with where the industry is?

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 technical accomplishments of the Silicon Electrolyte Interface Stability (SEISTA) program have been impressive. The project has focused on the systematic investigation of uniform model-Si samples. The reviewer asserted that this is a wise methodology since differences in Si frequently cause large changes in performance. The team has also utilized a wide array of novel analytical methods to investigate the materials. These novel methods have provided significant new insight into the surface reactivity and SEI stability of Si anodes.

Reviewer 2:
The project has made significant contributions toward fundamental understanding of Si-anode properties using a variety of SOA analytical techniques. This has been the salient feature of these investigations and kudos to the teams for doing an excellent job in achieving this objective.

The reviewer was kind of hoping that this high-powered talented team with significant resources and time will be coming up with a solution for the Si anode that will be ready for use in a long-life cell. However, based on the current data, it was not clear to the reviewer that the teams were able to achieve that goal.

Reviewer 3:
The presenter described a high-level overview of all projects occurring via the SEISTA program. Significant breakthroughs may have been achieved with regards to the Mg-salt addition to form the in situ Zintl phase. This project seems to have good results and has been a cross-cutting project between various subtasks.

Interesting differences between the model system and the particles were mentioned—with different mechanisms for the thin-film applied Mg-Si system compared to the electrolyte—and will need to be investigated. Various other projects were mentioned with limited success, such as forming Si-Ni and Si-Sn alloy materials.

Discussion of a new, bulk-metallic-glass, synthesis process via “splat quenching” was described although it was not clear to the reviewer how it differed from previous synthesis methods pioneered by 3M for induction melting and rapid quenching.

Reviewer 4:
The reviewer listed the following comments:

- "Lifetimes of full cells can be predicted using AIC (accumulated irreversible capacity) values determined from short half-cell experiments." Numerous studies have shown that there is often a knee in the capacity fade that may not show up for hundreds of cycles.
- Use of thin film samples with Mg is a great idea.
- Considering life history is a good idea, but there is no follow-up.
- Pathways are proposed for how these experiments can lead to improved batteries; for example, stabilizing Li silicide with the Zintl phase.
- Metallic glasses show promise for lowered SEI.
- Where is work on calendar life?

Reviewer 5:
Each project has good technical accomplishments: a lot of effort and good characterization. The reviewer would like to have seen more links between projects for general conclusions though.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
There are fantastic collaborations among team members, according to the reviewer.

Reviewer 2:
This is an overview of a large team project. The team clearly interacts regularly and utilizes the resources of different National Laboratories effectively. The projects leaders do a good job of coordination of the many different projects. Since the performance of Si anodes is dependent upon many different factors, a large team approach with many different researchers studying the same materials is very important for the development of a consistent understanding of these complicated materials.

Reviewer 3:
The reviewer stated that this is a well-coordinated team project that really leveraged the excellence of each laboratory.

Reviewer 4:
The projects appear to have clear alignment and collaboration between institutions.

Reviewer 5:
The reviewer said that it is good the team meets and is aware of the other projects within the broader effort. The rigorous sample and experimental control are great. Broader questions and hypotheses need to be stated more clearly, with an effort across projects to address common hypotheses.

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 research proposed by the SEISTA team appropriately addresses many of the remaining issues with Si anodes. The development of systematic testing protocols will be needed to understand the subtle differences in these systems. It was clear to the reviewer that developing a strong understanding of the SEI stability and mechanical properties will be needed to design superior interfaces. Some alloy and surface-modified data are

very promising, and the expansion of these efforts is merited. These proposed areas will likely lead to improved Si electrode systems for electric vehicle applications.

Reviewer 2:
The reviewer's reservation was whether the proposed work will lead to a commercially viable solution and be competitive with SOA Si technologies.

Reviewer 3:
This reviewer referenced the presentation—"Identify solutions to SEI stability based upon SEISTA understanding and direct"—and noted that this does not sound like there are any specific ideas for how to accomplish this.

Reviewer 4:
The presenter describes proposed future work from a very high level but did not describe actionable pathways or new projects that the team will undertake to address existing barriers. Significant gaps between the SEISTA program and commercial interests (5-10-year horizon) remain; the reviewer hopes that learnings from the SEISTA program will eventually be applicable to real-world scenarios.

Reviewer 5:
The future work listed on the slides is certainly necessary, but not specific enough. The reviewer agreed with the bullet—"Understanding the mechanical features of the SEI will be important."—and asked how. Which project will focus on that?

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

Reviewer 1:
According to the reviewer, this project supports the DOE objectives of developing lower cost, higher energy density LIBs for electric vehicles. The development of improved Si or Si-graphite composite anodes is one of the few viable methods to increase the energy density of the anode for LIBs. This team is addressing the important problems in an appropriate manner.

Reviewer 2:
The reviewer stated that Si is critical to the DOE roadmap. In spite of massive amounts of work by both industry and academia, problems are still not solved. We need the advanced characterization techniques being developed within this program to understand and solve the issues.

Reviewer 3:
LIB technology is a critical national security issue and one of the keys to achieving U.S. energy independence. It is well understood that Si-anode technology is vital to decreasing the costs of LIBs to threshold levels required to compete with IC engines for electric vehicles. The SEISTA program aims to address some of the shortcomings of Si technology in order to accelerate Si adoption, thereby leading to reduced battery costs and improved transition to electric vehicles. The reviewer commented that the exact projects researched under SEISTA in order to accelerate commercial Si adoption can be debated.

Reviewer 4:
This project is very relevant to overall DOE overall objectives.

Reviewer 5:
Calendar life, which is widely ignored, is explicitly examined here.

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

Reviewer 1:
The resources and the time provided for this project were significant and sufficient.

Reviewer 2:
Resources seemed sufficient to the reviewer and appropriate for this large, multi-organization project spanning five National Laboratories and many universities.

Reviewer 3:
The project is appropriately resourced.

Reviewer 4:
Resources are sufficient.

Reviewer 5:
The reviewer did not think it is possible to fully understand Si anodes in 2020. The milestones are quite specific, so doable. There are a lot of people working on this.

Presentation Number: bat437
Presentation Title: Silicon Electrolyte Interface Stabilization (SEISTA): Electrochemical Methods
Principal Investigator: Robert Kostecki (Lawrence Berkeley National Laboratory)

Presenter

Robert Kostecki, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

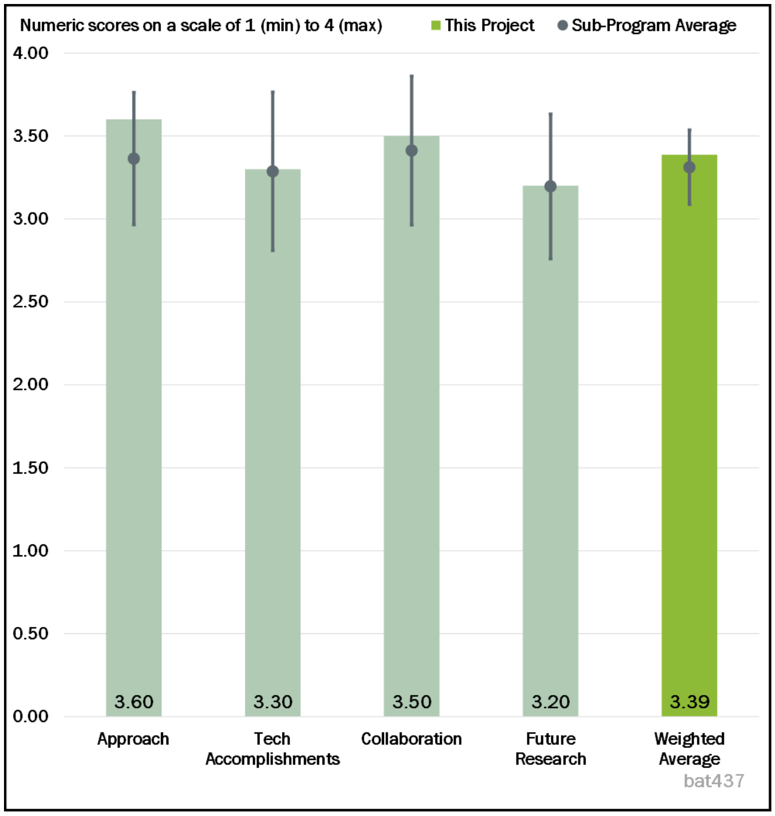

Figure 2-45 - Presentation Number: bat437 Presentation Title: Silicon Electrolyte Interface Stabilization (SEISTA): Electrochemical Methods Principal Investigator: Robert Kostecki (Lawrence Berkeley National Laboratory)

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 approach to investigating the SEI on Si anodes is excellent. The three main areas investigated are the most important topics for the further development of Si anodes for LIBs. The investigation of electrolyte modifications is an important area of focus. The investigation of CO_2 as an electrolyte additive is important, and the additional information obtained by this project is very useful to the battery community. The modification of the Si surface via Zintl-phase formation is both interesting and provides a platform for additional investigations. Finally, the approach of investigating alloys may lead to the development of additional novel materials.

Reviewer 2:

According to the reviewer, this project is well designed and hits at the core of the issue. The reviewer commented that Si stability and performance are heavy dictated by the surface of the material, and this project focuses closely on characterization of the surface of the materials.

Projects that were grouped into three strategies were undertaken to investigate Si-electrolyte interface. Although the three overall strategies to stabilize the Si-electrolyte interface are appropriate and cover the critical research topics for the SEI (active material *S*olid, *E*lectrolyte modifications, and *I*nterface modifications), it was not clear to the reviewer how the sub-projects to prove out the three strategies were decided and/or why they are the most promising paths to research.

Reviewer 3:
The work was very focused and well designed to characterize and understand the Si-anode properties.

Reviewer 4:
Slide 4 is excellent as it clearly highlights the important questions to be answered. There is one missing, though: how broad are the answers for different types of Si? But the reviewer appreciated the thoughtful approach to this work.

Reviewer 5:
The reviewer asked the team to please explain explicitly how these experiments can lead to an improved Si anode. That is, how does knowing details of SEI help in being able to get a better SEI? Additionally, the reviewer reported three approaches suggested to improve battery performance

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 carried out high-quality work to characterize the Si surface properties, especially the quantitative studies. This work clearly adds to our improved understanding of this electrode and how to manipulate it for practical use. This is also true for the new materials that were investigated in this project.

Reviewer 2:
The technical accomplishments directed toward electrochemical methods for investigating the SEI on Si are impressive. All three areas of focused study provided a stronger mechanistic understanding of the system of materials with significantly improved performance. The investigations of CO_2 as an electrolyte additive did not results in significant changes to the performance of the Si electrodes. However, changes to the composition and structure of the SEI were observed and a better understanding of the structure-function relationship of the SEI was established. The accomplishments related to the generation of a Zintl phase on the surface of the Si is promising. The reduction in residual current and the improved capacity retention are both promising. The development of novel Si alloys also provides promising results toward the use of Si-based materials in LIBs for electric vehicle applications.

Reviewer 3:
The technical development to answer questions is very well done. However, the reviewer thought that the specific systems studied are not necessarily going to answer all the questions on Slide 4. The focus on Zintl compounds and CO_2 may be too specific to academia. Is the industry considering either one? Maybe focus more on binder interactions—with more than LiPAA (which is not the most commonly used binder for Si in industry).

Reviewer 4:
The presenter described accomplishments for the three strategies that were undertaken. Unfortunately, the technical accomplishments did not pan out for the electrolyte project (CO_2 gas addition). Interface modification via introduction of Mg salt was also covered in other presentations. Electrochemical and NMR results shown in this presentation suggest promising results regarding Mg-Si bond strength although more data could have been presented. The amorphous Si-alloy material synthesis and testing results were similarly short and did not appear to show significant progress. Only first two cycles were reported, with no additional cycling. Also, it was not clear to the reviewer how the alloy improved the "mechanical stability" as mentioned on Slide 19; there did not appear to be data to support this conclusion.

Reviewer 5:
Correlating thin-film Si corrosion current with full cells is very important. Yi Cui's (*Nature Nano* 2012) hollow Si nanowires and Shaojun Guo's nanoparticles (J. Mater. *Chem. A*, 2018, 6, 8039) were coated with

SiO_x, and they got an extremely stable SEI on the SiO_x. But this project does not get stable SEI on SiO_x. Any thoughts?

It is not clear how NMR clarifies how the Zintl phase is formed on Si anodes. Any insights into how the Zintl phase stabilizes the interface? The reviewer also asserted that understanding why Si is different from graphite is very important. When the lithium ethylene decarbonate (LiEDC) disappears upon delithiation, does the team get the Li back? If so, it does not affect the CE.

Mn has a (bad) effect on SEI if it is present in the electrolyte (from dissolution of cathode). It does not need to be incorporated into the anode to have its effect. Possibly, Mg also does not need to be incorporated into the Si to have its effect; maybe its benefits can show up simply by being added to the electrolyte?

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This project benefited from excellent collaboration among the various teams.

Reviewer 2:
The reviewer stated that there was extensive collaboration, including round-robin testing.

Reviewer 3:
There appears to be significant collaboration between the teams. This is also evidenced by the similar results shown from many participating organizations for the projects.

Reviewer 4:
This project is a collaboration of many different researchers and utilizes the resources of the National Laboratories well. Much of the progress clearly involves research requiring teams of different researchers. The coordination of the different projects is strong.

Reviewer 5:
The reviewer found clear synergies between this project and others presented today. There are no issues with collaboration among the groups.

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:
According to the reviewer, the proposed future topics are of significant importance to the development of superior LIBs. The plan to utilize a round-robin approach for investigating the physiochemical properties is likely to lead to an improved understanding of the mechanism of SEI operation and function. This will also lead to a better correlation of interfacial properties with electrochemical performance. These fundamental investigations will provide the groundwork for the rational design of superior Si electrodes.

Reviewer 2:
There are interesting approaches that are relatively specific about just what next steps are called for.

Reviewer 3:
Item II on Slide 21 is the most important next step. There are good observations using analytical techniques, but are those observations relevant to solve the performance problems in a cell? The PI should make sure the round-robin electrodes in item I are industrially relevant.

Reviewer 4:
While the work is of very high quality, the reviewer was not sure the future research proposed will be able to reach overall DOE goal set out for this project

Reviewer 5:
The proposed future work is high level but lacks details on the direction in which the team will head. It is directionally correct but has no mention of risk mitigation, alternative development pathways, or decision points.

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

Reviewer 1:
Battery technology is a critical national security issue and key to achieving U.S. energy independence. The reviewer remarked that Si-anode technology is required to achieve LIB cost thresholds for electric vehicles to compete with IC engines. SEISTA and this project aim to address shortcomings with Si technology, thereby accelerating Si adoption and leading to reduced battery costs and improved U.S. global competitiveness.

Reviewer 2:
This project supports the DOE objectives of developing lower cost, higher energy density LIBs for electric vehicles. The development of improved Si or Si-graphite composite anodes is one of the few viable methods to increase the energy density of the anode for LIBs. This team is addressing the important problems in an appropriate manner.

Reviewer 3:
This project supports overall DOE objectives since the improved Si anode will lead to a significantly higher energy density cell.

Reviewer 4:
The reviewer indicated that Si is an important component to address energy-density targets for the DOE roadmap. A lot of work has been done in it (industry and academia), but we are still not there. This work needs to be completed and linked to commercially relevant materials and approaches.

Reviewer 5:
The project is relevant.

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

Reviewer 1:
Resources seem sufficient and appropriate for this large multi-organization project spanning six National Laboratories and many universities.

Reviewer 2:
The resources allocated to this project are sufficient to complete this project in a timely manner.

Reviewer 3:
The project is sufficiently resourced.

Reviewer 4:
The reviewer asserted that this is a huge team and a big project. The project will not gain much by adding even more.

Reviewer 5:
Resources are sufficient.

Presentation Number: bat438
Presentation Title: Silicon Electrolyte Interface Stabilization (SEISTA): Advanced Characterization
Principal Investigator: Glen Teeter (National Renewable Energy Laboratory)

Presenter

Glen Teeter, National Renewable Energy Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

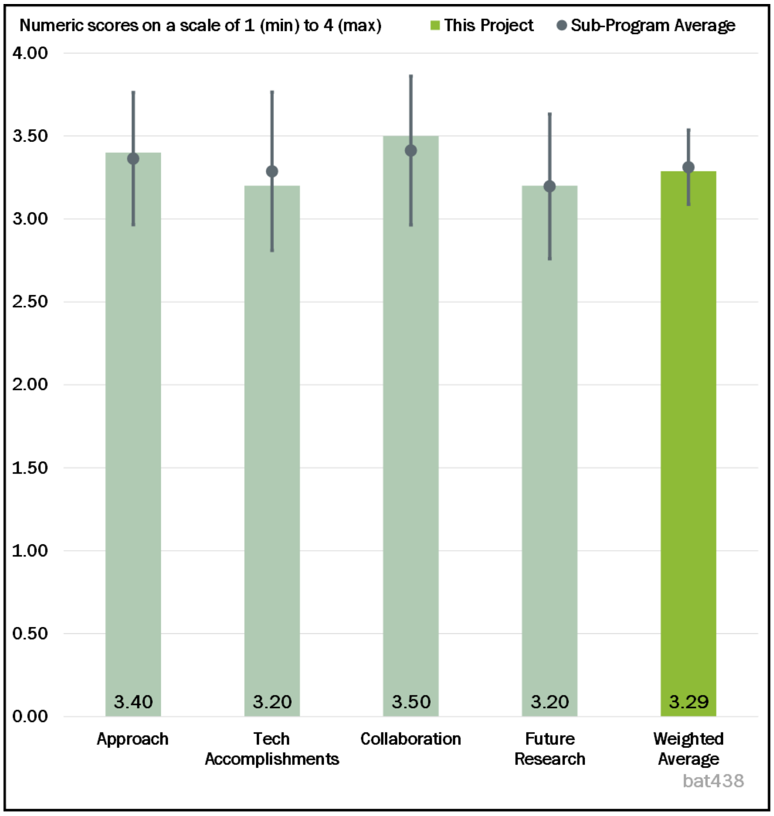

Figure 2-46 - Presentation Number: bat438 Presentation Title: Silicon Electrolyte Interface Stabilization (SEISTA): Advanced Characterization Principal Investigator: Glen Teeter (National Renewable Energy Laboratory

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:

According to the reviewer, the approach to investigating the surface of Si particles for Li- battery anodes is excellent. The team uses many different in situ and ex situ techniques for investigation of these important materials. Many of these techniques utilized the resources of the National Laboratories and have had little application toward battery materials. This approach utilizes the novel expertise of the team to develop a better understanding of these important battery materials.

Reviewer 2:

This part of the SEISTA program hits at one of core issues for Si stability (characterization) and aims to conduct in situ and in operando characterization of materials. These characterization techniques are important because they provide the best insight into the operating cells.

Reviewer 3:

The approaches involve cutting-edge tools to characterize the Si electrode.

Reviewer 4:

The development of many useful characterization techniques for such difficult systems is extremely valuable. The reviewer did not think the presentation showed enough how those techniques have helped answer any questions about Si failure mechanisms. For example, the XPS in situ lithiation of SiO_x-Si showed how the composition affects the over-potential. It would be good to then relate this to what might happen in a real cell for various Si-active materials.

Reviewer 5:
The reviewer is very much in favor of calendar-life studies, where breakthroughs in performance and understanding seem more likely than in cycle life, which has been studied intensely already. But the reviewer saw no work on it.

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 advanced characterization tools used (neutron reflectometry, surface-enhanced Raman spectroscopy [SERS], XPS, etc.) here are exceptionally suitable to shed light on the fundamental processes at Si-electrolyte interfaces. The data are very insightful and SOA. Very impressive!

Reviewer 2:
Many of the novel techniques utilized provide significant new results and understanding of the SI SEI. The in-situ SERS provides interesting insight into the formation, dissolution, and decomposition of the SEI on Si anodes. Related matrix-assisted laser desorption/ionization time-of-flight investigations of electrolytes containing vinylene carbonate reveal systematic changes to the SEI, including the generation of polymeric and oligomeric species. These results are both interesting and novel. In particular, the novel in situ XPS results provide significant insight into the evolution of the Si surface upon lithiation and delithiation.

Reviewer 3:
Significant results were shown although they did not seem to be distilled into conclusions or concrete results. The reviewer was left wondering what the Impact was of the tests or how to use the characterization results to design better materials and move the industry forward. For example, there was not much discussion of the impact or takeaways of using the in-situ neutron reflectometry experiment or what the team hoped to achieve with the investigation; the story is similar for the in-situ SERS.

Although the work is great, it was not clear to the reviewer what the Progress or Accomplishments were with the investigations. There was a slight bit of connection between the time of flight - secondary ion mass spectroscopy measurements and the XPS analysis but any new learnings or breakthroughs are lacking. The most interesting results (Li diffusion along the Si-silicon oxide interface) may have been due to impurities and were not substantially investigated.

Reviewer 4:
Again, the reviewer found good progress on the development of techniques. But those techniques now need to be applied to the right systems to address the issues on Slide 3.

Reviewer 5:
A microbalance can measure the thickness of SEI, operando, with much more sensitivity and much greater ease than neutrons.

The focus here on SEI composition brings up this question: After so many studies of SEI composition, have we learned anything useful? Why does the team expect useful results to come from Si-SEI studies?

The Li+ ion gun is novel and sounds exciting. But the reviewer does not understand what the team is learning that can apply to Si electrodes.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The project is characterized by excellent collaboration among the team members.

Reviewer 2:
There is good collaboration between teams across the project. The reviewer noted that work was spread out between organizations and participating partners and was highlighted in the presentation.

Reviewer 3:
The results presented are part of a multi-laboratory collaboration. The collaboration and coordination between National Laboratories are good and has afforded the generation of novel and important results.

Reviewer 4:
This project involves a lot of techniques, which necessitates different researchers with different expertise. The group seems to be working well together to deliver advanced characterization techniques to this effort.

Reviewer 5:
The reviewer is not sure that this project benefits from cross-pollination of ideas between labs; each project seems to be working on its own.

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 the expected transition to “real-world” samples and the need to conduct “future studies on model systems where they can provide clear answers to key questions.” The reviewer found that statement to be extremely important and suggested that significant effort should not be applied to studies where there are not clear learnings that can be used to advance fundamental understanding. Future work is headed in the right direction, but there is no mention of decision points or alternative development pathways to ensure the team is focusing on the most promising techniques to solve pressing issues.

Reviewer 2:
The proposed work is a continuation of the results that have been generated. The team will continue to expand the utilization of the novel techniques developed for the investigation of Si anodes. These additional investigations will likely lead to the generation of additional important observations.

Reviewer 3:
The reviewer focused on bullet point #3 on the Future Work slide. That might not yet be possible with all the techniques, but the team could prioritize those that are most mature.

Reviewer 4:
These tools are great, but the reviewer was not sure the overall DOE objective for this project will be achieved by this work (of the whole effort).

Reviewer 5:
The reviewer found the proposed projects on Slide 18 to be vague: “Future studies on model systems will continue where they can provide clear answers to key questions.”

There are lots of composition measurements already in the literature about SEI species. What new is the team expecting from these experiments? What will the team do with the information that it gets?

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

Reviewer 1:
The reviewer remarked that LIBs are critical to our energy independence, and Si plays a large role in improving EV adoption by decreasing battery costs. In order to accelerate Si adoption, a fundamental

understanding of the materials must be achieved. This project aims to improve the fundamental characterization of Si.

Reviewer 2:
This project supports the DOE objectives of developing lower cost, higher energy density LIBs for electric vehicles. The development of improved Si or Si-graphite composite anodes is one of the few viable methods to increase the energy density of the anode for LIBs. This team is addressing the important problems in an appropriate manner.

Reviewer 3:
The reviewer stated that Si anodes are an important component in achieving DOE roadmap energy-density targets. This project seeks to understand and improve the performance of Si.

Reviewer 4:
The project supports the overall world doing objective by improving Si anode.

Reviewer 5:
The project is relevant.

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

Reviewer 1:
The resources and time given to this project were significant and sufficient.

Reviewer 2:
The resources seemed appropriate to the reviewer to achieve the stated milestones. There is access to enough resources (time, money, and equipment) to make significant progress toward milestones. The projects just have to be well designed, managed, and stage-gated to increase probability of success.

Reviewer 3:
This is a big team, and resources seem adequate to continue.

Reviewer 4:
Resources are sufficient.

Reviewer 5:
The project is properly resourced.

Presentation Number: bat439
Presentation Title: Silicon Deep Dive: Silicon-Based Slurries and Electrodes
Principal Investigator: Beth Armstrong (Oak Ridge National Laboratory)

Presenter

Beth Armstrong, Oak Ridge National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

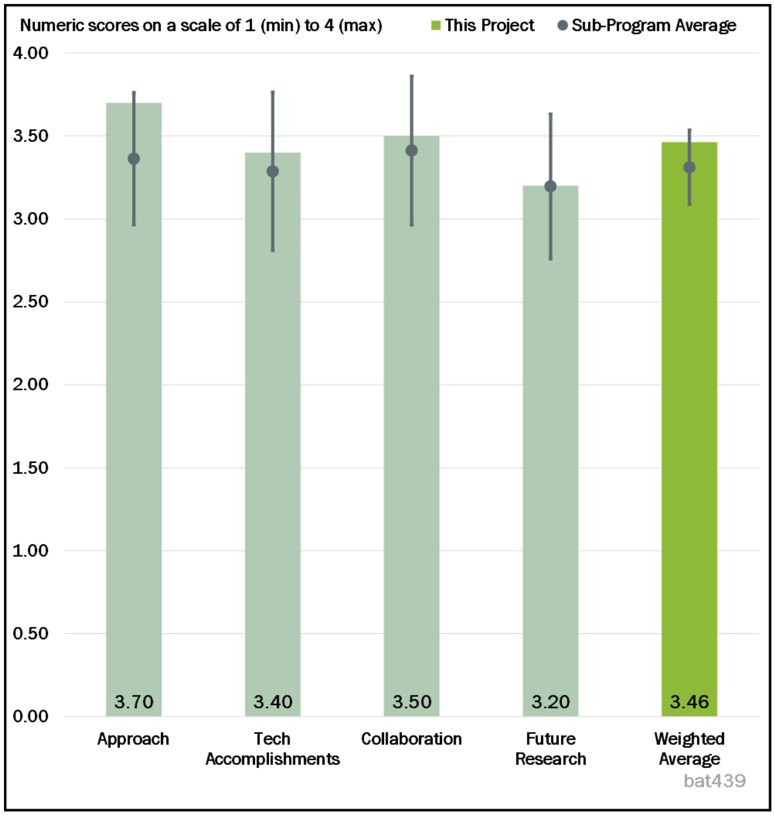

Figure 2-47 - Presentation Number: bat439 Presentation Title: Silicon Deep Dive: Silicon-Based Slurries and Electrodes Principal Investigator: Beth Armstrong (Oak Ridge National Laboratory)

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 this was a very well planned and focused project that tried to better understand the factors that govern Si-anode coating variables, which are very critical to developing very stable Si electrodes.

Reviewer 2:

The presenter sufficiently described an approach to improving Si-based slurries and electrodes. Technical barriers were addressed (consistent protocols, electrode rheology, and additives to control attractive forces). The project appeared to the reviewer to be well designed and feasible and details the characterization methods used to conduct the project.

Reviewer 3:

The approach to systematically investigate the interrelations between the liquid-solid interfaces to control electrode homogeneity and performance is very important to the battery community. The utilization of a multi-laboratory effort to develop consistent protocols and develop a better understanding of processing is critical for battery applications in electric vehicles. In addition, since surface modification of Si particles has recently developed as an important area for material-performance enhancement, developing a better understanding of surface modification on rheology is important.

Reviewer 4:

Rheology has not been beaten to death in the literature like so many other efforts to improve batteries. Studying homogeneity is important.

Reviewer 5:
It is critically important to understand the slurry and casting process of electrodes. The reviewer asserted that we do not sponsor enough of this. The work on recovery time is very important to today's manufacturers and can be an important means to get better battery performance.

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 praised the accomplishments and progress as excellent. The work on how the Si surface changes the aggregation and structure of the binder in solution is particularly interesting and can be applied to commercial systems. This is immediately useful to industry.

Reviewer 2:
This project has led to quite a few very impressive results and insights that will be highly useful in developing a very efficient Si electrode. The studies on stress, rheology, and binder behavior as a function of Si-surface properties; use of tomography; and Si-surface functionalization have been nicely carried out and results lucidly explained.

Reviewer 3:
The technical accomplishments are strong. Binders have been reported to have a large influence on the properties of Si anodes. The results suggest that the surface of the Si particles has a large effect on aggregation and binder structure. The results also show that optimization of the mixing and slurry chemistry can be used to optimize electrode homogeneity. Both of these results are important for the development of Si anodes for LIBs.

Reviewer 4:
The reviewer asked how electrode homogeneity affects battery durability or other battery properties. In general, how does the team relate these measurements to performance? The reviewer thanked the project team for trying not to repeat what the reviewers have already seen in other talks. Additionally, the reviewer commented that rheology analysis is very valuable for improving how electrodes can be made more reproducible. Unless cesium (Cs) is well dispersed in the binder, using Cs to locate binder is flawed.

Reviewer 5:
The presenter described technical accomplishments in regard to electrode development although the reviewer noted that significant questions remain. There are many variables that must be covered to ensure appropriate electrode formulation (adhesion, cohesion, peel strength, porosity, inactive volume, electrical resistance, thermal resistance, etc.), which did not seem to be taken into account with the data presented in the technical accomplishments.

There is no linkage between the mixing procedure to produce these laboratory-scale electrodes and those that are produced at a pilot scale and/or commercial level. The results shown in the presentation may not be relevant to practical mixing equipment.

The characterization results (X-ray nanotomography, rheology, etc.) were interesting and well done, but more effort must be exerted to ensure that electrodes are completely mixed properly and are applicable to practical equipment. For example, commercial applications typically do not use more than 1% carbon black anymore and often use very small amounts of carbon nanotubes (CNTs). Therefore, some of the X-ray nanotomography and rheology results are not broadly applicable beyond this specific project and the electrodes that were prepared. Additional characterization techniques (electrical resistance, impedance, etc.) could have also been used to determine the quality of electrode coatings.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The project made efficient use of the expertise of the collaborating team members for synthesis, analysis, and modeling, among others.

Reviewer 2:
This is a multi-laboratory effort, which clearly utilizes much collaboration and coordination. The team has done a good job with coordinating the different efforts.

Reviewer 3:
The large team is fairly well coordinated, and communication looked appropriate to the reviewer.

Reviewer 4:
The reviewer found good collaboration across laboratories.

Reviewer 5:
There appears to be good collaboration and coordination across projects. Although it was not explicitly mentioned in the presentation, significant collaboration between ORNL and ANL's Cell Analysis, Modeling, and Prototyping (CAMP) Facility could prove beneficial for electrode and slurry-processing development.

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 on rheology, surface modifications, or process improvements will contribute well to the body of good data developed so far.

Reviewer 2:
The future direction is oriented toward developing a better understanding of the relationship of SEI stability on electrode formulation. The reviewer noted that this will be one of the critical areas for further developing Si anodes. The team will also direct effort toward the development of better processing methods in order to generate more homogeneous laminates. These efforts are also important for the development of Si anodes for Li batteries for electric vehicles.

Reviewer 3:
The reviewer said that this is a good approach to continue. It would be good to always compare with results from a standard graphite system. Are the observed results and relationships unique to Si?

Reviewer 4:
Proposed future research was appropriate although somewhat vague and high level (for example, "Continuous feedback to team doing fundamental work."). The reviewer suggested that project members reach out to cell-manufacturing experts to learn more about critical processing parameters to accelerate learnings. This project has access to very powerful equipment and should be applied to cutting-edge electrodes and materials. The presenter was aware of some of these issues and acknowledged some of them on the Critical Assumptions & Issues slide so they can hopefully be addressed soon.

Reviewer 5:
Most of the future research statements are pretty vague: for example, on Slide 18, "Understanding of rheology and impact on formulation and performance." What, specifically, does that mean?

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

Reviewer 1:
This work is very relevant to the DOE overall objectives since an improved Si anode will lead to increased cell energy density ability.

Reviewer 2:
This project is relevant because it is focused on Si-anode technology, which has been identified as a key driver to decrease battery costs and increase EV adoption (a key DOE objective).

Reviewer 3:
This project supports the DOE objectives of developing lower cost, higher energy density LIBs for electric vehicles. The development of improved Si or Si-graphite composite anodes is one of the few viable methods to increase the energy density of the anode for LIBs. This team is addressing the important problems in an appropriate manner.

Reviewer 4:
The reviewer stated that Si is an important component to achieve DOE's energy-density roadmap for automotive applications. There needs to be more understanding to get Si to work and achieve targets.

Reviewer 5:
The reviewer said that the project is relevant.

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

Reviewer 1:
The resources allocated to this project are significant and sufficient.

Reviewer 2:
Resources are appropriate and sufficient to achieve program milestones.

Reviewer 3:
The project is sufficiently resourced.

Reviewer 4:
Resources seemed sufficient to the reviewer.

Reviewer 5:
The reviewer commented that resources are sufficient.

Presentation Number: bat440
Presentation Title: Silicon Deep Dive: Silicon Functionalization
Principal Investigator: Zhengcheng Zhang (Argonne National Laboratory)

Presenter

Zhengcheng Zhang, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Project Relevance and Resources

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

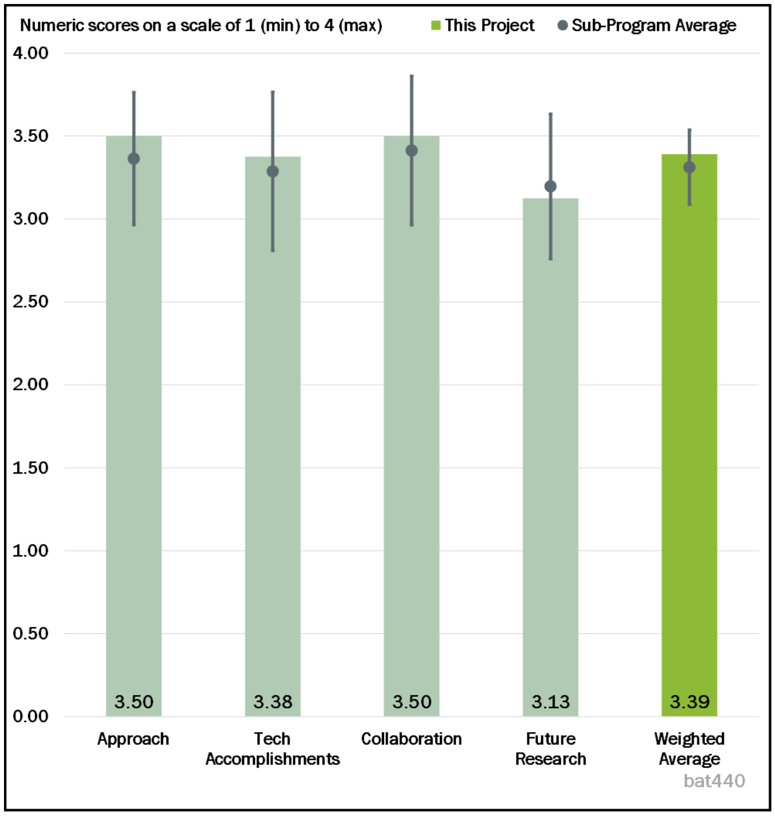

Figure 2-48 - Presentation Number: bat440 Presentation Title: Silicon Deep Dive: Silicon Functionalization Principal Investigator: Zhengcheng Zhang (Argonne National Laboratory)

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 presenter focused on two main strategies to improve materials performance—active-material surface stability and electrolyte development. These strategies provide a practical approach to improving materials performance in categories that are most likely to improve Si-anode performance (SEI improvement). Strategies address key technical barriers (calendar life and cycle life), and the reviewer remarked that the project appears well designed and feasible.

Reviewer 2:

The reviewer stated that the approach to surface modify Si particles to improve the interfacial properties is both interesting and useful. The proposed method to etch the surface to generate Si-H bonds followed by hydrosilylation reactions utilized well-developed synthetic methods to make functional materials. The choice of different types of grafting agents is useful for the systematic development and investigation of novel materials.

Reviewer 3:

The concept of functionalizing Si nanoparticles to create an SEI could be a good approach, according to the reviewer. The systematic evaluation of functional groups that are expected to perform in different ways looks very effective. It would be good to show that the functional groups help on the varying types of Si.

Reviewer 4:

Numerous studies have functionalized Si nanoparticles. The reviewer would like to have seen what is new and/or different here—some comparison to what is already in the literature.

Looking for new electrolytes is very valuable.

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 presenter provided impressive results on surface modification of Si particles and the resulting electrochemical performance. The reviewer observed that Si particles treated with various materials (ethyl carbonate, epoxy, ethylene oxide, etc.) seemed to show major increases in the average CE, which should translate to improved SEI and Si-cycle life. Surface modification led to reduced electrode swelling and reduces impedance growth. As a follow-up, it would be interesting to learn if the surface-modified Si materials also suffer from the "SEI dissolution" issues described in other projects. It would also be interesting to investigate if these surface modifications lead to thinner and more stable SEIs (especially the epoxy-modified Si particles), or if these materials can be integrated with the Mg-salt addition (Zintl phase) to also further compound improvements to SEI and cycle life.

Additionally, the work on the high-concentration electrolytes, fluorinated ethers, and deep eutectic solvents appeared unique and promising. The presenter described results showing 500 cycles to 80% capacity retention, which is impressive although it was not clear to the reviewer if these would provide a practical energy-density improvement in their current format. Most importantly, it would be good to know how these electrolytes behave for improving calendar life—one of the key barriers the team is addressing with this project.

Reviewer 2:

This project had a lot of work done on it, with sound conclusions. It involved functionalization of the particles, characterization, and testing, which means a lot of effort every time the chemistry is changed. There are good accomplishments.

Reviewer 3:

The technical accomplishments are interesting and beneficial. A series of different sidechains were grafted onto the Si particles. The reactions appear to generate novel surface films, and some of the novel surface films provide performance enhancements. The team was also able to generate mixed surface films, which are quite interesting. According to the reviewer, the team should have commented on the potential cost of these surface modifications and whether this can be done in a cost-effective manner. The novel electrolyte formulations are also interesting and show promising results.

Reviewer 4:

The reviewer offered the following comments and questions:

- Hybrid, functionalized Si nanoparticles are a terrific idea, but the first cycle loss is too high and CE is too low. How can this approach be improved?
- The new electrolyte shows good life, but specific capacity (Slide 15) is extremely low, around 100 mAh/g. Why? Is there a zero missing from the y-axis?
- Is there any work on calendar life? Should not the calendar-life work be the first project to get attention so that the experiments can last for a few years?
- It was not clear how much of the SEI problems are due to chemistry and how much to mechanics. Is this issue being considered?

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The presenter highlighted good collaboration across the six DOE National Laboratories for this integrated effort. Also, there was explicit mention of coordination between ANL core facilities and with interactions within the Si Deep Dive program.

Reviewer 2:
The project is a collaboration between multiple National Laboratories. There appears to be both good coordination and much collaboration within this project, according to the reviewer.

Reviewer 3:
This project has a lot of people collaborating and seems to coordinate well. In particular, the reviewer thought that this project covered a lot of different skill sets.

Reviewer 4:
The reviewer remarked that five to six labs are participating.

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 builds on the existing projects and provides directionally clear work to be performed. The reviewer stated that the proposed research did not discuss specifics, risk mitigants, or decision points for stage-gating projects moving forward.

Reviewer 2:
The reviewer suggested trying more functional groups to gain understanding and improvement before spending a lot of time on scale-up.

Reviewer 3:
The reviewer said that no specifics are provided.

Reviewer 4:
While the team proposed to continue the investigation of surface-modified Si particles and the development of novel electrolytes, the team could have provided more specific directions for the future research.

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

Reviewer 1:
This project is relevant because it is focused on battery technology, which is a critical national security issue and key to achieving U.S. energy independence. The reviewer noted that Si-anode technology is required to achieve LIB cost thresholds to compete with IC engines for EVs. This project aims to accelerate Si development, thereby accelerating EV adoption and improving U.S. global competitiveness in energy storage.

Reviewer 2:
This project supports the DOE objectives of developing lower cost, higher energy density LIBs for electric vehicles. The development of improved Si or Si-graphite composite anodes is one of the few viable methods to increase the energy density of the anode for LIBs. This team is addressing the important problems in an appropriate manner.

Reviewer 3:
The reviewer remarked that Si anodes are an important component in the DOE roadmap for improved energy density for automotive applications. The issues with Si have not been solved even though a lot of work has been done. This work supports fundamental understanding required to ultimately solve the problems.

Reviewer 4:
The reviewer said that Si electrodes are relevant.

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

Reviewer 1:
Resources seemed sufficient to the reviewer and appropriate for this multi-organization project spanning six National Laboratories and additional academic partners.

Reviewer 2:
Resources are sufficient.

Reviewer 3:
The project is sufficiently resourced.

Reviewer 4:
Overall, the reviewer thought that the Si-anode Deep Dive has enough resources and would like to see this specific effort enhanced over some of the others.

Presentation Number: bat441
Presentation Title: High-Performance Electrolyte for Lithium-Nickel-Manganese Oxide (LNMO)/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

100% of reviewers indicated that the project was relevant to current DOE objectives, 0% of reviewers indicated that the project was not relevant, and 0% of reviewers did not indicate an answer. 80% of reviewers indicated that the resources were sufficient, 20% of reviewers indicated that the resources were insufficient, 0% of reviewers indicated that the resources were excessive, and 0% of reviewers did not indicate an answer.

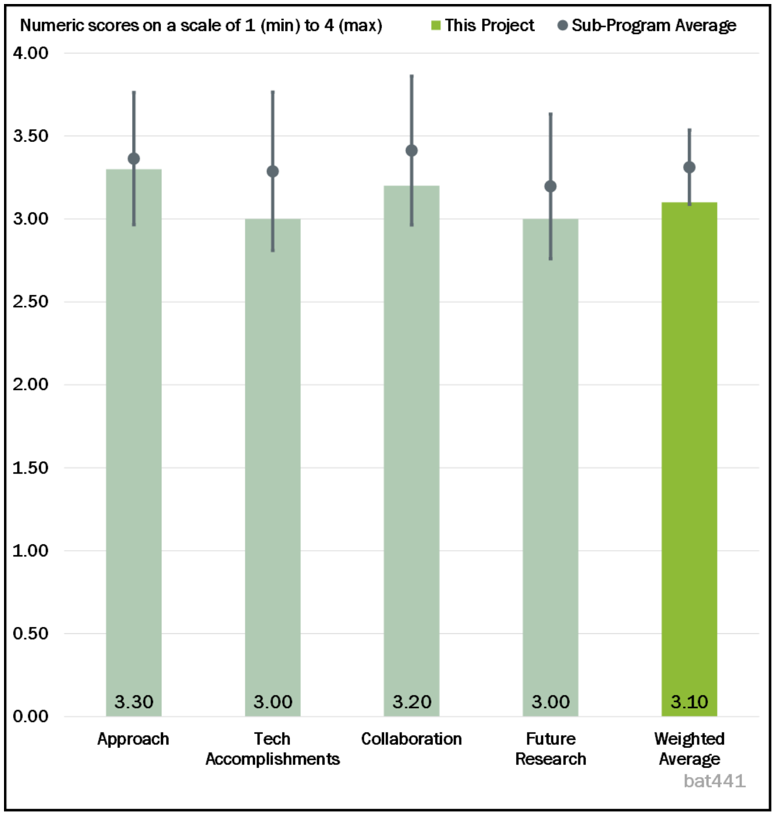

Figure 2-49 - Figure 2 49 - Presentation Number: bat441 Presentation Title: High-Performance Electrolyte for Lithium-Nickel-Manganese Oxide (LNMO)/Lithium-Titanate (LTO) Batteries Principal Investigator: Jennifer Hoffman (Gotion)

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 praised the approach as the best one seen so far. The team plans to investigate a number of additives for a number of different properties, including conductivity, stability, and gas suppression. It hopes to learn what aspects of the additives lead to what types of impacts on critical electrolyte properties.

Reviewer 2:

The project team has identified the critical technical and cost barriers associated with the Li batteries. The reviewer stated that the relevance of the objectives and its impact is clearly mentioned. The team has developed a multi-layer, pouch-cell test to understand the intricate details and documented it well. This is a well-designed and feasible approach.

Reviewer 3:

The main strategy of the project is to select and synthesize electrolytes that work best for a LMNO-lithium titanate (LTO) battery. The team's major approach, as seen in the presentation, is routine tests on the electrolyte properties and electrochemical performance. The reviewer remarked that this might be a feasible route but not with novel technologies.

Reviewer 4:

The reviewer appreciated the approach being taken but wondered what about this approach is novel compared to historical attempts to overcome these challenges. The difference in this project compared to the past should be called out in the future.

Reviewer 5:
The project aims to enable LTO-LNMO battery chemistry as a way to overcome performance barriers for high energy density and long life as well as address the cost barrier to the high-performance batteries needed in longer range EVs. The limited scope of the project, however, limits its ability to address the performance barriers, and there is really no obvious way the work will address the cost barrier based on the information provided.

On the latter cost goal, the only reference to cost was that LTO is more expensive than graphite, and LNMO is potentially cheaper than NMC622 due to zero Co, with the trade-off in costs potentially being slightly favorable, perhaps? A later reference in the property gap chart indicated that electrolyte costs are to be less than $10/kg, but it was certainly not clear to the reviewer how the cost barrier of high-performance batteries will be addressed by small tradeoffs in the cost of materials. Furthermore, the cost advantage of LNMO will start to decrease as NMC811 is adopted and/or other low-Co cathodes. There may not be much room for cost reduction here.

For the first barrier of high-energy-density performance, the selection of LTO-LNMO is a reasonable choice to address the barrier, but the project's almost sole focus on electrolyte additives to solve all of the problems (some of which are clearly popping up in the early tests with LNMO/C) is a bit shortsighted. If the problems with high-voltage cathodes (and LTO as well) were limited to gassing, then this approach would probably be fine.

The reviewer asserted that the team on this project is excellent, and the University of Rhode Island (URI) in particular is a well-known leader in studying and mitigating gassing reactions. There is no one better to take on gassing issues. But, the instability of the electrolyte with high-voltage cathodes involves far more coupled, non-equilibrium electrochemistry and calls for a more comprehensive approach to solving the problem than hoping that an additive package can stop gassing and passivate the surface of the LNMO.

The work here will contribute to the solution in all likelihood, but it is unlikely to make much headway against the high-energy-density/long-cycle-life barrier by itself. In the end, the team will be able to screen about a dozen additives, have to down-select that list based on what can be scaled in synthesis, further down-select that list by what showed promise in the screening, and get to test only one, two, or maybe three additives in 2-Ah and 10-Ah multi-layer pouch cells (MLPCs).

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:
Overall, the reviewer said that the technical accomplishments for the project are good. The gap chart for advanced electrolytes and performance parameters is clearly populated, and the investigative approach to understand the performance of each parameter is clearly mentioned. The team has showed good technical progress measured against the performance indicators.

Reviewer 2:
Some additives improve one aspect of the electrolyte while others help another aspect. The team is still searching for the optimal additive.

Reviewer 3:
Work is ongoing as is in-depth analysis. Some initial correlations are seen. More work is needed for structure-property relationships.

Reviewer 4:
Because of the impact of COVID-19 and U.S.-China relations, some of the tasks were delayed or extended.

Reviewer 5:
The project has made some progress: for example, an additive (one of three tried) for reducing LTO gassing was found. The approach of using NMC622 as the cathode in these tests to isolate the LTO-gassing performance was very good. The corresponding 2-Ah pouch cells were tested and showed good results, another positive step in the right direction. However, the reviewer stated that progress on the LNMO (isolated testing with C as the anode) does not seem to have fared well, and results for these tests (Slide 9) were notably poor. The team claimed that progress was still made because it learned a lot about the gassing and other degradation mechanisms, but this vague assertion is hard to quantify. It does not seem to have triggered a new innovative idea for an additive, at least not one that was mentioned. So, the progress of the project is going to be affected by these results.

The LNMO/C cells were on the project's critical path and a delay in this work while the problems are worked out will also delay the end of the project. Progress on measuring the intrinsic properties of the electrolyte was also made, but again it was not clear to the reviewer if any progress was made on optimizing and/or balancing the obvious tradeoffs, like specific conductivity versus vapor pressure. Slide 8 has lots of yellow, but also has some gray where apparently measurements have yet to be made.

As a note to the team, the Overview slide says that the project runs from March 2019 to March 2022, which is a 3-year time frame, but the PI said that it was a 2-year project. The PI also said, "it's still early in the project" and "when we get to the middle or nearer the end of the project." If the project is indeed 2 years, then the project is past its mid-point, and progress will have to be greatly accelerated to even fully characterize the performance advantages of the electrolyte additives that have already been identified as potentially beneficial in an actual LTO-LNMO cell.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The team is working with Brett Lucht's group at URI in trying to understand the impact of different additives.

Reviewer 2:
The team seems to rely on each member to move the project forward.

Reviewer 3:
The collaboration and coordination between Gotion and URI appear to be very good. It was not clear to the reviewer how much of the work is being done where, but the pace of activities does not seem to be limited by the logistics of such a collaboration. This is not always the case in even a two-partner collaboration, so it is good to see that the partnership seems to be doing very well.

The problem with 10-Ah testing was not really clear. Was it vaguely due to some issues with Gotion's expansion overseas? Anyway, URI is probably well positioned to find the necessary resources for its partner if the current plan also fails to work out.

Reviewer 4:
The reviewer stated that the involvement of an academic institution in this collaborative effort is good in terms of understanding the fundamental aspects, but the addition of DOE National Laboratories would enhance the development process.

Reviewer 5:
Collaboration with URI is declared, but no activities are reported so far and the project is said to be already 45% completed (which is an exaggerated statement).

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 overall approach proposed for future research seemed okay to the reviewer; however, the key step as to why this will suddenly lead to an improvement not yet achieved by others is missing.

Reviewer 2:
The reviewer did not see any difference between the Approach and the Proposed Future Research. There is a slight difference in electrolyte intrinsic property study between the Approach and proposed future study.

Reviewer 3:
The tasks listed in the "Approach" slide about MLPC testing are exactly the same as that in the slide for Proposed Future Research. The reviewer could not tell which parts are completed and which parts are future works. The poster was not carefully prepared.

Reviewer 4:
The team still needs to test additional additives in NMO/C and NMO/LTO cells. This methodical approach is critical to finding an answer, according to the reviewer.

Reviewer 5:
The apparent plan is to move ahead with the 2-Ah MLPC with LTO-LNMO in parallel with continuing the C/LNMO work to solve the capacity-loss issues observed so far. It was not clear to the reviewer that parallel development will be all that effective or useful. How can the LTO/LNMO cells be properly evaluated if major issues with electrolyte stability with the LNMO cathode at 4.9 V have not been addressed?

It was also not clear to the reviewer, with the time remaining, that the 10-Ah MLPC test can be completed as envisioned. This might be a good time to take stock of the progress to date and the opportunities to address the most significant issues in a reasonably large pouch cell and restructure the project to focus on the highest impact outcomes. Making a 10-Ah MLPC that is not likely to cycle longer than 100-200 cycles due to electrolyte decomposition, CEI formation, impedance rise, etc., at the cathode might not be the best plan going forward.

It is not really clear what the team has learned in the initial tests (details were withheld), but it is not likely that enough was learned to regain the original schedule and finish all of the planned testing within the original time frame of the project. This is just a guess based on the information in the poster.

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

Reviewer 1:
The project clearly supports and is well aligned with specific DOE objectives for advancing EV battery technology and enabling vehicle electrification. As some point, high-energy cathodes (e.g., 4.9 V) will have to be commercialized to support ever-increasing performance requirements for EV batteries, and this work could provide at least a portion of the answer if a few beneficial additives for LTO and/or LNMO can be identified and demonstrated at some level of testing.

Reviewer 2:
The reviewer noted that the objective of the project is to boost performance of LNMO-LTO batteries, which supports the DOE objective.

Reviewer 3:
Developing a fundamental understanding of high-voltage stability and improved conductivity of electrolytes with additives is critical to advancing many novel, high-energy systems, which are critical to DOE's mission.

Reviewer 4:
Electrolyte development is critical for DOE to achieve its electric vehicle targets.

Reviewer 5:
The reviewer said that the research presented does meet the DOE overall objectives.

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

Reviewer 1:
The project team has allocated sufficient resources to perform the research and achieve the stated milestones in a timely fashion, according to the reviewer.

Reviewer 2:
The reviewer asserted that the $1.5 million in DOE support is enough for all these proposed routine tests.

Reviewer 3:
The resources available have allowed for meaningful advancement.

Reviewer 4:
Resources are sufficient.

Reviewer 5:
It is possible that the resources (funding) are available to complete the project and achieve key milestones, but an extension of the project timeline is probably going to be required (partially due to pandemic shutdowns on laboratories).

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

Presenter

Anthony Burrell, National Renewable Energy Laboratory

Reviewer Sample Size

A total of two reviewers evaluated this project.

Project Relevance and Resources

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

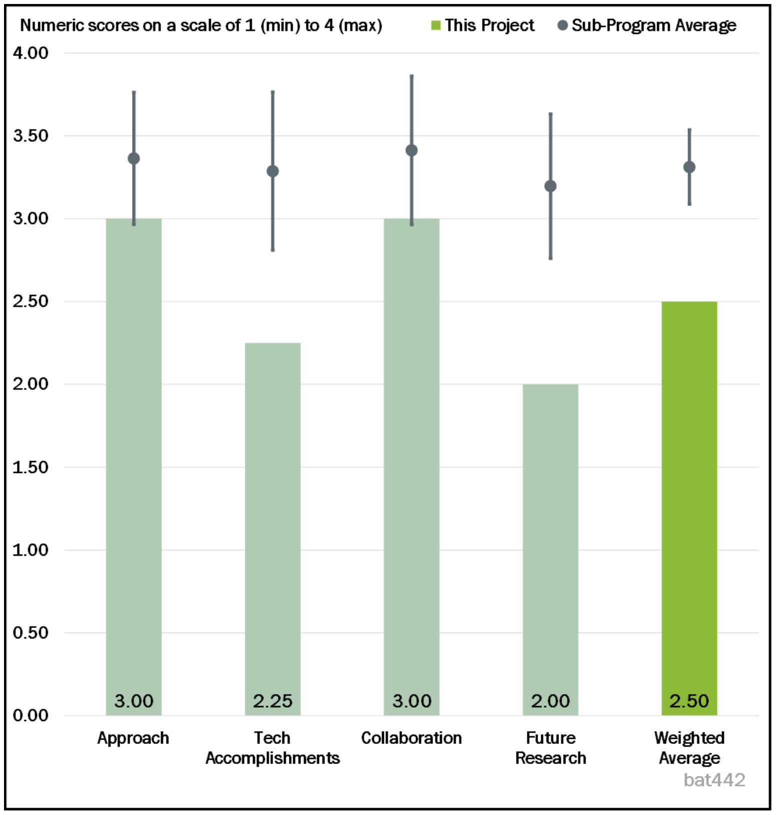

Figure 2-50 - Presentation Number: bat442 Presentation Title: Behind-the-Meter-Storage (BTMS) Overview Principal Investigator: Anthony Burrell (National Renewable Energy Laboratory)

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 PI did an excellent job of describing the breadth of the challenge. What could be improved is the definition of what success on the project would look like. An example of a quantitative assessment would be helpful. It will otherwise be difficult to assess when the project is complete.

Reviewer 2:

Most of the presentation was an overview of the problem and what they hoped to address. The role of each National Laboratory was not clear to the reviewer. How the money was distributed was not mentioned nor were deliverables defined. The presenter basically said it is a large, complicated problem that will require a lot of work for a solution and made it clear that this is not a battery for the grid nor is it a battery for a vehicle. It is some form of energy storage for a combination of photovoltaics (PV), building loads, and EV fast-charge requirements. The team needs to figure out the value proposition of such a system.

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 a $2.5 million project with four National Laboratories, and the team is basically still laying out the problem. The reviewer saw very few accomplishments after a year and a half of effort. If funded at $2.5 million in 2019, that’s nearly $4 million. Essentially, the team has defined a problem so complicated that it did not appear to the reviewer that the team knows where to start or how to solve it. This should have been funded at a much lower level until the team figured this out.

Reviewer 2:
There are several parallel work streams. The reviewer said that it would be helpful to have shown, for each work stream, the targeted deliverables and decision points over the length of the project. The PI could better describe how results from the individual work streams are synthesized. An example would be the down-selection of the electrochemical storage technology and the thermal energy storage technology, and then how those two would be optimized, given the constraint of the big box store, mall problem.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Coordination appeared to be good. Highlighting who was taking the lead for each of the particular sub-projects would be beneficial. This could either be placed against the task on each slide, or provide a summary in the front, as to which participant is delivering what.

Reviewer 2:
The reviewer asserted that the collaboration is difficult to rate because work from any one institution was never pointed out. Again, most of the presentation was about the problem. How the problem was broken down and distributed to the different National Laboratories is never discussed.

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 referred to prior comments while stating that the PI should be clear on how the parallel paths will be synthesized, as well as what the major risks are on each of the parallel paths. A slide describing how negative outcomes and positive outcomes can be gamed in order to determine potential best solutions would be helpful.

Reviewer 2:
There was no future directions slide. There was some analysis of how to treat thermal energy storage and how it was analogous to electrical energy storage, but there were no clear tasks laid out as to next steps and who would be doing what.

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

Reviewer 1:
The project is an excellent example of balancing multiple key technologies' developments with the overall DOE objectives.

Reviewer 2:
The reviewer assumed that the DOE objectives are to move to a sustainable ecosystem. Trying to figure out how to do this while satisfying the needs of everyone is a huge challenge. These folks have identified a particularly difficult barrier that is worth investigating.

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

Reviewer 1:
The project appears to be adequately staffed and supported. The project could spin off additional projects, however, and then those need to be evaluated for appropriate staffing and support.

Reviewer 2:

The reviewer's guess was that most of this early work is being conducted at NREL, but from the presentation it is anybody's guess. The reviewer had no idea how many folks are working on this problem, but it is quite a large budget. The reviewer was not sure how the team is going to see itself to the end. It seems that perhaps after 3 years the team will have the problem mapped out where it can start coming up with some design parameters for the entire system.

Presentation Number: bat444
Presentation Title: Highly Loaded Sulfur Cathode, Coated Separator, and Gel Electrolyte for High-Rate Lithium-Sulfur Battery
Principal Investigator: Yong Joo (Cornell University)

Presenter

Yong Joo, Cornell University

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

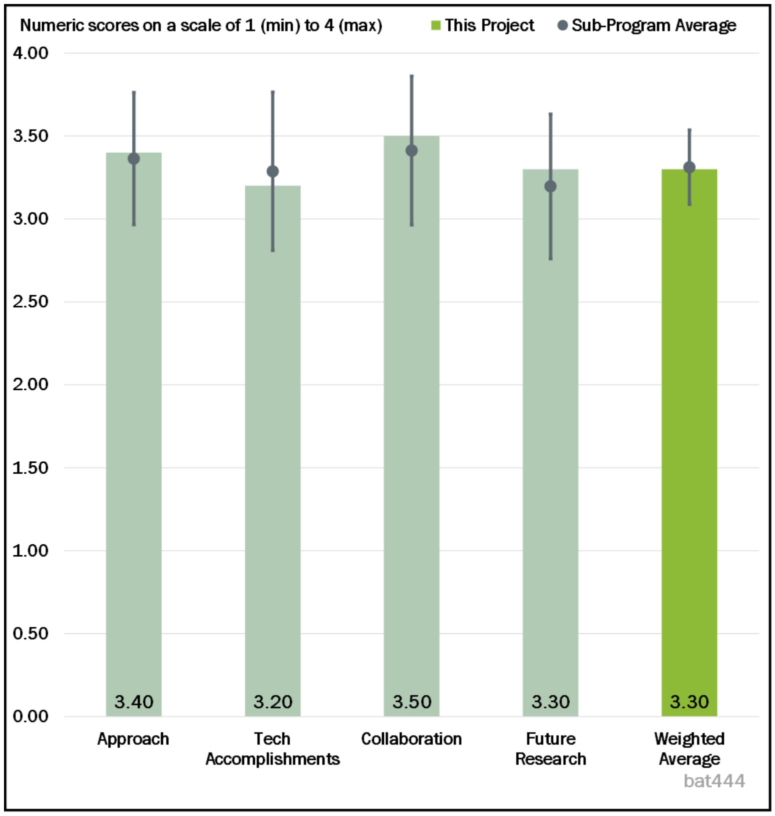

Figure 2-51 - - Presentation Number: bat444 Presentation Title: Highly Loaded Sulfur Cathode, Coated Separator, and Gel Electrolyte for High-Rate Lithium-Sulfur Battery Principal Investigator: Yong Joo (Cornell University)

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:

There are multiple approaches in this work to develop a high-loading, high-rate, and longer cycle life Li-S battery.

The approaches include layer-on-layer electrospray method, graphene and ceramic separators, and gel electrolyte to prevent polysulfide dissolution and prolong cycle life.

The approaches are comprehensive and on multiple fronts to address the common issues in the Li-S battery.

Reviewer 2:

The project team used three approaches to overcome some key barriers of a S system. The method of incorporating S in graphene is novel and creative. Coating the separator with carbon and gelling the electrolyte will reduce the shuttle effect but will not completely overcome this barrier. Also, use of Li metal is still a major issue that limits the cycle life. The expectation is that by applying these three approaches, one can extend the cycle life to 500 cycles, thus making this system potentially applicable in some applications.

Reviewer 3:

The target of the project is to achieve high-rate Li-S batteries at high-energy conditions. There are many scientific and engineering barriers that need to be addressed toward that target, such as high S loading, reaction kinetics of the S cathode, Li-ion transport in both the liquid electrolyte and solid products, and the shuttling reactions of Li-polysulfide. In this project, the reviewer stated that the PI is aware of the challenges and has proposed effective approaches to solve those barriers. For example, the team used an electrospray method for multiple-layer cathode preparation to enhance the cathode electronic conductivity, did separator coating to suppress polysulfide crossover, and employed a gel-electrolyte concept to trap polysulfide in the cathode side.

The reviewer said that one important point needs to be carefully considered when proposing the approaches: the impacts of the approaches on the cell energy. For example, S content in the whole cathode, electrode porosity, mass loading of the separator coating, total weight of the gel electrolyte, and liquid components should all be controlled and minimized in order to achieve the proposed energy of 500 Wh/kg.

Reviewer 4:
The PI and collaborators reported a graphene-coated separator and gel electrolyte to prevent or slow down the dissolved polysulfide ions reaching the Li anode. The research aims to mitigate the shuttle effect caused by the dissolved polysulfide species. The gas-assisted electrospinning process for the thin-layer coating seems to be working and could be scaled up to a production process. The gel electrolyte certainly can slow down the mass transfer of the polysulfide ions.

The reviewer asserted that the PI needs to explain better why a graphene-coated separator can block the migration of polysulfide ions. The electronic conductive coating could result in the cell shorting.

Reviewer 5:
The PI used a combination of S cathodes, separator modification, and gel electrolytes to significantly suppress the shuttle effect and improve the cycle life and rate performance. Nevertheless, the current, areal-capacity loading (less than 3 mAh/cm^2) and electrolyte-S ratio (not clear to the reviewer) both need to be further improved to increase the practical energy-density goal for Li-S batteries in the future.

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 has made satisfactory technical accomplishments, according to the proposed milestones:

- The S cathode loading has been optimized through a layer-by-layer approach and graphene nanoribbon coating.
- The ceramic-polymer separator with graphene coating has been successfully fabricated and showed improved rate capability.
- Initiation of gel electrolytes for Li-S batteries.

Reviewer 2:
The team made good progress and is on track to complete the tasks and milestones on time.

For the electrode task, the reviewer found the results of 3-mg/cm^2 loading, S-electrode performance at 900 mAh/g at 0.2C rate to be quite reasonable. The team also demonstrated the effectiveness of layer-by-layer approach to enhance rate performance. For the separator task, the cell-testing results demonstrated the effectiveness of the hybrid separator. For the gel-electrolyte task, the gel electrolyte provides better performance than conventional electrolyte.

Reviewer 3:
The team has demonstrated the positive effect of each technique separately and will be combining the effect of the three concepts in future work. The reviewer noted that the team expects some good results.

Reviewer 4:
Overall, the PI has made good progress during the review period. The project team also achieved milestones on time and on track to accomplish all the required milestone for the remaining time of this fiscal year. The

electrospray technique was successfully used to prepare the multiple-layer S cathode and functional separator coating. The prepared S cathodes showed significantly improved cycling stability. The separators with functional coatings were able to suppress the polysulfide crossover. The S content in the whole electrode as well as the mass loading of separator coating should be provided for a clear justification. Also, the reviewer commented that the relative electrolyte amount, i.e., the electrolyte-S ratio for the cell test, should be provided.

For the ceramic cross-link gel electrolyte, the PI indicated that the gel electrolyte helped to improved capacity retention and rate capability. However, all the discharge curves provided in the report showed higher electrochemical polarization for the cells using a gel electrolyte compared with those with a liquid electrolyte.

Reviewer 5:
In comparison with the control cell, the approaches did cause better results in term of capacity retention during cycling. The 3 mg/cm^2 was adequate and 0.2C rate was lower than 0.5C, which was in the objective, but it demonstrated that 0.5C was attainable.

The pore-size distribution could be improved. The reviewer asked that, first, please use log scale X and, second, how was the electrode degassed and was S in it?

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
According to the reviewer, the team is complementary and works closely with the tasks well defined for each team member.

Reviewer 2:
The reviewer commented that this is an excellent collaborative effort including academia and industry. The academic collaborator is from Cornell University, and the industry collaborator is from EIC Laboratories. Each collaborator is responsible for certain activities as defined in the Collaboration slide.

Reviewer 3:
The PI has excellent collaboration and coordination with university and industry partners. The reviewer suggested future collaborations with other Battery500 teams in order to accelerate the integration of the achieved success for a practical battery demonstration.

Reviewer 4:
The team is well balanced with academic investigation and full-cell, scale-up developments.

Reviewer 5:
The collaboration and coordination across the project team have not been well demonstrated yet.

The reviewer could not find any joint publications with the co-PI or other 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 team will study the combined effect of Si-graphene, carbon-coated separator, and the gelling of the electrolyte. The team has shown positive results for each process. The reviewer expected that the performance of the cell—based on the combined three technologies—should be interesting.

Reviewer 2:
The proposed future work on high-S loading electrode, gel electrolyte, and development of pouch cells is made up of all-important tasks to pursue.

The target performance is also defined for each task and milestone.

The reviewer said it is reasonable to anticipate that the team can achieve most of the target by the end of the project.

Reviewer 3:
The proposed future research plan is reasonable. Integration test of the electrode and separator assembly would be helpful to identify real challenges that need to be addressed. Before the cell-safety test, the reviewer suggested that the PI first demonstrate Li-S pouch cells with practical high energies by using the developed materials and technologies.

Reviewer 4:
The PIs plan to optimize the synergistic integration of all cell components and scale-up to a 3-Ah full-pouch cell in the future. The plan is consistent with the proposed milestones.

The question is the safety test. A safety test only makes sense if a well-engineered cell is made. So, the reviewer suggested doing the safety evaluation in the end.

Reviewer 5:
Increasing the areal S loading is for sure required to increase the practical energy density of Li-S batteries toward 500 Wh/kg.

However, the electrolytes-S ratio (weight of gel electrolytes in this project) needs to be significantly decreased.

The reviewer did not see a plan or consideration on this from the PI.

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

Reviewer 1:
This project is very relevant to DOE’s objective in energy storage: high energy, long lifetime, low cost, and use of earth-abundant materials.

Reviewer 2:
According to the reviewer, the development of long-lasting, high-energy-density Li-S batteries is clearly relevant to DOE goals.

Reviewer 3:
Given the high theoretical energy density and extremely low cost of S, Li-S battery technology is one of the most promising battery technologies for future vehicle electrification and even for grid energy storage.

Reviewer 4:
The project supports the overall DOE objective since it relates to the development of a high-energy, low-cost S system that can enable mass electrification of vehicles.

Reviewer 5:
This project has a plan to improve the electrochemical performance of Li-S batteries by increasing S loading, suppressing the shuttle effect, and enhancing the reaction kinetics.

With further optimization of the electrolyte- S ratio, the reviewer said it could potentially enable the DOE energy goal on Li-S 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 believed that resources are sufficient to achieve the stated milestones in a timely fashion.

Reviewer 2:
The resource is sufficient to the work performed and planned.

Reviewer 3:
The PI at Cornell has adequate resources for the fundamental investigation and developments, while EIC has the capability of scale-up to pouch cells.

Reviewer 4:
The PI has all the resources for cathode preparation, separator modification, gel-electrolyte preparation, and pouch-cell fabrication.

Reviewer 5:
The reviewer commented that there are sufficient resources for the project to achieve the stated milestones in a timely fashion if the team closely works with the industrial partner or other Battery500 teams.

Presentation Number: bat445
Presentation Title: Multifunctional Lithium-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 three reviewers evaluated this project.

Project Relevance and Resources

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

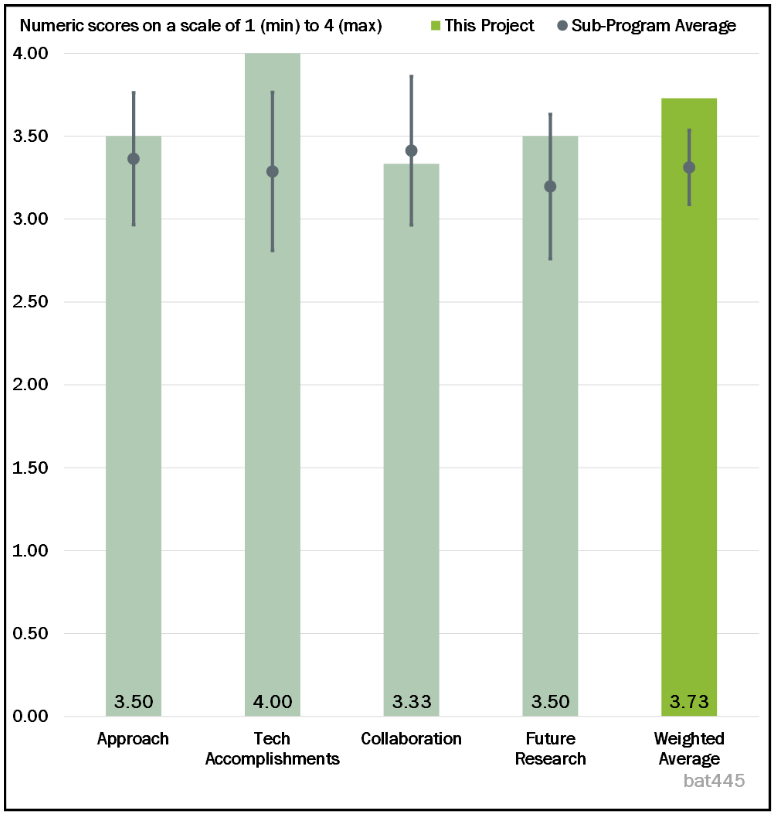

Figure 2-52 - Presentation Number: bat445 Presentation Title: Multifunctional Lithium-Ion Conducting Interfacial Materials for Lithium-Metal Batteries Principal Investigator: Donghai Wang (Penn State University)

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 well designed with two approaches to overcome the technical barriers. First, a bottom-up design using a reactive polymer composite (RPC) to enable excellent cycling performance under lean electrolyte with limited Li excess and high capacity.

Second, using an electrochemically active monolayer (EAM) strategy to efficiently improve the Li-metal battery performance at low temperature (-15°C). Suppressing dendrite formation during Li-metal deposition is very important for high-energy-density battery development but is an extremely challenging topic. The reviewer found that this project addresses such critical problems with well-designed approaches.

Reviewer 2:

Bottom-up design approaches were adopted to tackling the stability issue of a metallic Li anode. In the project, both an RPC and EAM were utilized to suppress the growth of Li dendrite. The advantage of these approaches is that the formation of the protective layer was driven by thermodynamics. However, the components used were electrochemically active or electronically conductive. The reviewer stated that the potential impact of residual electronic-conductive components is unknown.

Reviewer 3:

This work has demonstrated the effectiveness of the approach to use a polymeric ionomer to form an artificial SEI layer in combination with modified graphene oxide (GO). The team has designed and synthesized a new class of F- containing precursor polymers, which can convert into a Li-ion ionomer during the Li-deposition process. The GO is also used to provide additional adjustment to the properties of the artificial SEI layer.

Stabilizing Li-metal deposition is an important thrust to enable a Li-metal electrode. Designing an artificial SEI layer has been very actively pursued by many researchers in this field. The team has demonstrated through testing that their SEI layer design has significantly improved stability of Li-metal compared to the baseline system.

The reviewer remarked that the presentation needs to address two issues: the function of the GO materials and the interaction of the polymer with GO materials; and the mechanism of Li-ion transport in this composite layer.

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:
Outstanding progress has been made toward the overall project. This project demonstrated two impressive accomplishments. First, it observed that thin RPC-derived SEI, distinct from conventional electrolyte-derived SEI, enables uniform Li deposition upon long cycling. Stable cycling (over 200 cycles) of a 4-V Li|NCM523 battery cell was achieved under lean electrolyte (7 microliters [µL]/mAh), limited Li excess (1.9-fold excess of Li), and high areal capacity (3.4 mAh/cm^2). The polymer-inorganic structure of the RPC-derived SEI confers good stability and effective suppression of electrolyte decomposition based on the NMR studies, and the results were published in *Nature Materials.*

Second, the electrochemically active EAM modification on Cu provided an LiF-rich inner phase and amorphous outer layer, which efficiently improve the cycling performance of Li-metal batteries at -15°C. At low temperature (-15°C), the Li@EAM Cu anodes demonstrate dramatically improved cycling performance, which is comparative to the performance at 25°C.

The reviewer saw these technical achievements and progress as outstanding against performance indicators.

Reviewer 2:
The team has made significant progress in the first year of the research. The team came up with a design of the polymer precursor and GO composite, synthesized the polymers, and put them into cell testing in a variety of different cell designs and chemistry. The team also reported excellent performance of the materials and cells tested. A variety of analysis techniques is used to understand the polymer-composite, artificial SEI layer before and after the deposition. The reviewer said that the team also came up with a convincing explanation of the function of the artificial SEI layer.

Reviewer 3:
The reviewer noted that outstanding interfacial stability was demonstrated.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The PI of this project, Professor Donghai Wang, has great collaboration with Dr. Alan Goliaszewski at Ashland Specialty Ingredients G.P. on the scale-up fabrication of the Li-ion conducting polymer; with Dr. Ji-Guang Zhang at PNNL on fabrication and testing of Li metal batteries; as well as with Dr. Anh Ngo on computational modeling from ANL. The reviewer saw the collaboration and coordination across the project team of this project as excellent.

Reviewer 2:
Excellent collaborative work with industry and National Laboratories. Each collaborator's function is clearly defined.

Reviewer 3:
The team maintains a good collaboration with National Laboratories and an industrial partner.

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 project has effectively planned its future work and the milestones for the remaining time of this project; these are well thought out and a logical continuation of earlier milestones.

Reviewer 2:
The proposed future work is focused on understanding Li-nucleation and improving performance of the SEI layers. These are important directions for this project, according to the reviewer. The future work also provides numerical goals to accurately measure the performance enhancement.

Reviewer 3:
The team has a good plan for future work, mostly driven by the performance parameters. It will be of great interest to the reviewer to see how the team investigates the impact of the protective chemistry.

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

Reviewer 1:
According to the reviewer, this work greatly supports the development of high-energy-density battery technologies using Li metal.

Reviewer 2:
This project is very relevant to the DOE objective in the energy storage area to enabling high-energy-density batteries.

Reviewer 3:
The reviewer found this project to be highly relevant and supportive of DOE objectives to develop an affordable, high-energy-density battery for electric vehicles. There is still a challenge to achieve dendrite-free plating and stripping of Li with high-cycling efficiencies. This will be required to achieve long cycle life required for affordability. The effort is addressing this issue.

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 resources of this project are sufficient to achieve the milestones on time.

Reviewer 2:
Resources are sufficient to conduct the proposed task.

Reviewer 3:
Resources are sufficient for the work performed and planned.

Presentation Number: bat446
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 three reviewers evaluated this project.

Project Relevance and Resources

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

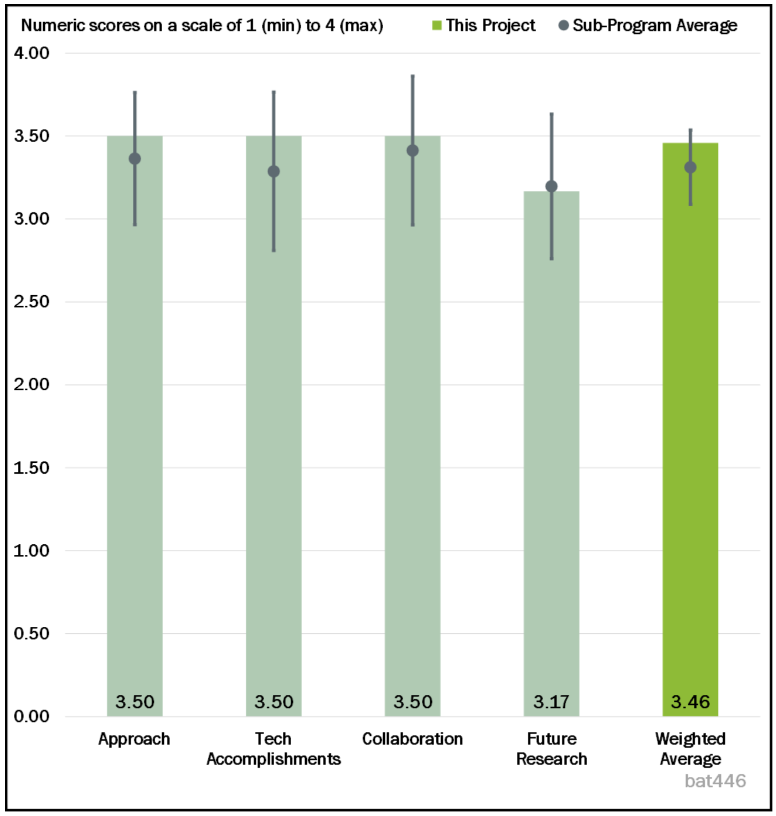

Figure 2-53 - Presentation Number: bat446 Presentation Title: Electrochemically Stable, High-Energy Density Lithium-Sulfur Batteries Principal Investigator: Prashant Kumta (University of Pittsburgh)

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 well designed with multiple approaches to overcome the technical barriers of low CE, limited cycle life, and poor rate capability of Li-S batteries:

- Generation of composite framework materials (CFM) enabling high-S loading and polysulfide (PS) confinement
- Interface engineering of CFM-S by homogeneous, non-porous, high electronic-conducting (EC) and Li-ion conducting (LIC) conjugated Li-polymer S- containing polymer (CLi-P-SCP) PS dissolution-resistant coatings to confine PS in order to improve the cycle life and rate capability
- Development of novel 3-D architecture electrode using EC- and LIC-coated CFM-S of targeted capacity (greater than 6 mAh/cm^2) using 3-D printing to achieve the desired architecture (control porosity and thickness).

This reviewer found that this project addresses such critical problems with well-designed approaches.

Reviewer 2:

The project developed multiple approaches to achieve a high-loading, high-S utilization, and longer cycle life Li-S battery. The reviewer found the approach of using a catalyst to rapidly convert polysulfide to lithium sulfide (Li_2S) to be very appealing. In the novel 3-D electrode, approach and high porosity are beneficial to the cycling performance and to achieve higher area loading. However, higher porosity could negatively impact the volumetric energy density of the battery.

Reviewer 3:
The project seemed well defined to the reviewer to address overcoming barriers to the technology. There is an approach presented to advance technology and efforts to address and overcome barriers.

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 team has made excellent progress in this review period.

On the materials front, the team developed complex framework materials and used lean electrolyte and Battery500 protocols to test the cells. On the interface front, the team developed electronic-conductor-coated and Li-ion conductor coated complex framework materials that showed improved performance. The team also performed 3-D printing to generate a high-S loading electrode and demonstrated improved cycling performance. The team also developed functional catalysts to convert polysulfide into Li_2S and leveraged computational capabilities to understand the mechanism.

Reviewer 2:
Some progress has been made toward the overall project. This project showed several technical accomplishments:

- XPS analysis shows that the content of polysulfides on the CFM separator was significantly lower than the commercial reference after multiple cycling.
- EC-coated CFM of nano-crystalline porous architecture shows the ability to trap PS and to improve the areal capacity.
- LIC-coated CFM of nano-crystalline porous architecture show an excellent ability to trap PS with improved areal capacity.

These achievements are significant. However, they are scattered in several research areas and lack a focused effort to reach the overall goals of this project. The reviewer sees that these technical achievements and progress are good against performance indicators.

Reviewer 3:
The project seemed to the reviewer to be on track toward the target milestones.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This is a truly collaborative effort including academia and industry. The academic collaborator is from the University of Pittsburgh; the industry collaborators are from Malvern Panalytical, Kurt J. Lesker Co. and Flex Cellz. Each collaborator’s role is clearly defined.

Reviewer 2:
It seemed to the reviewer that a good team has been assembled to address the identified barriers to the technology.

Reviewer 3:
The PI of this project has good collaborations and coordination.

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:
According to the reviewer, there seem to be a solid plan and pathway to developing the test cells for DOE performance characterization.

Reviewer 2:
The project has effectively planned its future work in developing a high-loading electrode, fabricating pouch cells, and further developing a 3-D electrode. It is planned in a logical manner by incorporating appropriate targets of 6- mg/cm^2 loading and a 100-mAh cell. The team understands technology barriers to the realization of the proposed goals.

The proposed future work on high-S loading electrode and developing pouch cells is made up of all-important tasks. However, the reviewer commented that the strategy of a catalyst to facilitate conversion of polysulfide to Li_2S and Li_2S_2 is a very attractive approach to minimize polysulfide dissolution. More work needs to be performed in this topic.

Reviewer 3:
This project team has reasonably planned its future work, and the milestones for the remaining time of this project are somewhat well thought out and a logical continuation of earlier milestones. The reviewer asserted that the problem with the future plan is the lack of focused effort to achieve the overall goal of this project.

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

Reviewer 1:
This project is relevant and supportive of DOE objectives to develop an affordable, high-energy-density battery for electric vehicles. There is still a challenge to achieve Li-S batteries with high CE, long cycle life, and good rate capability. The effort is trying to address such challenges.

Reviewer 2:
This project is very relevant to objectives of DOE in energy storage: high energy, long lifetime, low cost, and use of earth-abundant materials.

Reviewer 3:
Yes, this project supports the DOE objective of developing high Wh/kg battery technologies.

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

Reviewer 1:
Research proposed seemed to the reviewer to be well matched with the allocated funds.

Reviewer 2:
The resources are sufficient to the work performed and planned.

Reviewer 3:
The reviewer found the resources of this project to be sufficient to achieve the milestones on time.

Presentation Number: bat447
Presentation Title: 3-D 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 three reviewers evaluated this project.

Project Relevance and Resources

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

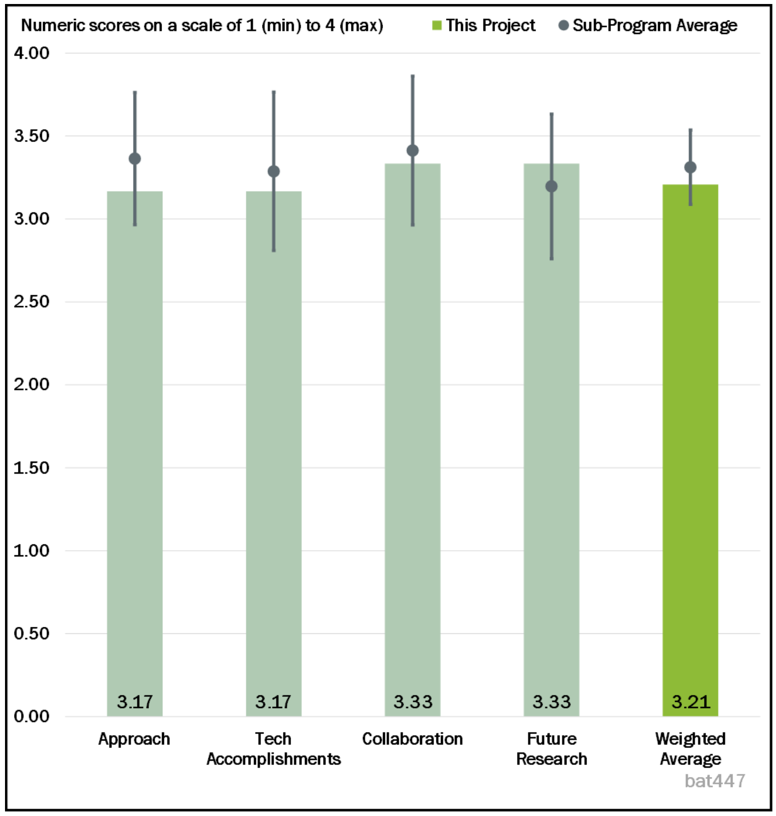

Figure 2-54 - Presentation Number: bat447 Presentation Title: 3-D Printed, Low-Tortuosity Garnet Framework for Beyond 500 Wh/kg Batteries Principal Investigator: Eric Wachsman (University of Maryland)

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 work has demonstrated the effectiveness of using 3-D structures of garnet-type, solid-state, superionic Li-ion conductors in the electrode. The project has extended the 3-D structure in both the anode and cathode. The 3-D approach is realized with 3-D printing techniques. Due to the extended surface area, a 3-D based, solid-state electrode is a reasonable approach to achieve high energy density on the cathode side and to slow down Li-dendrite formation on the anode side. The reviewer remarked that 3-D printing is also a scalable approach for future manufacturing.

One aspect that the PIs need to consider is the brittleness of the garnet materials. The ceramic materials and 3-D structures lack flexibility for scaling up to a larger and multi-layer battery.

Reviewer 2:

This project is well designed with three approaches to overcome the technical barriers, such as low interfacial surface area for the thick electrode and poor rate capability for solid-state batteries:

- First, develop solid-state ionic and electronic-transport models to optimize the structure and experimentally validate models
- Second, develop 3-D printing techniques and fabricate high-porosity, low-tortuosity $Li_7La_3Zr_2O_{12}$ (LLZO)-garnet structures
- Third, fabricate and demonstrate high-energy-density, 3-D printed, solid-state batteries.

The reviewer found this project addresses such critical problems with well-designed approaches.

Reviewer 3:
Most of the approach looked fine to the reviewer. However, the PIs did not respond to the questions posed by the reviewers, thus making it very difficult to evaluate their 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 PIs have made significant progress this year. A 3-D printing method was successfully used to make the 3-D electrodes of two different structures. The electrodes with 3-D structures demonstrated performance improvement in the testing cells. Modeling is successfully used to understand the current and field distribution to aid the 3-D structure design.

Electrodes with high loading of ~4 mAh/cm^2 of the cathode were fabricated and tested at 60°C at reasonable current density of 30 mA/g (~C/5).

Reviewer 2:
According to the reviewer, excellent progress has been made in the overall project. This project showed several technical accomplishments:

- Developed ink compositions to optimize rheology, as well as drying and sintering conditions to 3-D print multiple, low-tortuosity LLZO structures
- Achieved sintered approximately 200 µm LLZO column height on bilayer garnet structure
- Developed conformal coating of CNT inside garnet pores, which created a mixed electron-ion conducting framework to enable “Li-free” anodes
- Used a sputtered Cu-layer on the exterior surface of the porous LLZO layer to provide electrical contact for Li deposition as Li rises toward the dense layer during plating
- Fabricated and demonstrated full cells with a 3-D printed LLZO cathode.

These achievements are quite impressive for reaching the overall goals of this project. The reviewer saw these technical achievements and progress as excellent against performance indicators.

Reviewer 3:
The achievements are good; however, it was difficult to clarify several of them as the PIs were nonresponsive to the reviewers’ questions.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The project seemed very well coordinated to the reviewer, and there is one collaborator.

Reviewer 2:
The PI of this project has very good collaborations.

Reviewer 3:
This is mainly a university project with professors at the University of Maryland.

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 the PIs showed an excellent plan for the final year of the project.

Reviewer 2:
The proposed future work is focused on the 300-Wh/kg and 500-Wh/kg battery fabrication and testing. These are important directions for this project, according to the reviewer. The future work also provided numerical goals to accurately measure the performance enhancement.

The PIs need to define clearly how the 300 Wh/kg and 500 Wh/kg are calculated. Is this a cell-level number including all components or just the cathode anode and electrolyte? What is the cell capacity, besides energy density?

Reviewer 3:
Future work for this project is well planned, and the milestones for the remaining time of this project are well thought out and a logical continuation of earlier milestones. According to the reviewer, a problem with the future plan is the lack of detailed approaches to achieve the overall goal of this project.

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

Reviewer 1:
This project is relevant and supportive of DOE objectives to develop an affordable, high-energy-density battery for electric vehicles. There is still a challenge to achieve all solid-state batteries with long cycle life and good rate capability. This project is well designed to address such challenges.

Reviewer 2:
The reviewer found this project to be very relevant to DOE objectives in energy storage—a high-energy-density, safe, and long cycle-life battery.

Reviewer 3:
The plan stated in the Summary slide goes along with the objectives of 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 said that resources are sufficient for the work performed and planned.

Reviewer 2:
The resources of this project are sufficient to achieve the milestones on time.

Reviewer 3:
The team seems to have the proper equipment, and visits to the team's laboratories corroborate this. However, the funding seemed somehow high to the reviewer.

Presentation Number: bat448
Presentation Title: Advanced Electrolyte Supporting 500 Wh/kg Lithium-Carbon/Nickel Manganese Cobalt (NMC) Batteries
Principal Investigator: Chunsheng Wang (University of Maryland)

Presenter

Chunsheng Wang, University of Maryland

Reviewer Sample Size

A total of five reviewers evaluated this project.

Project Relevance and Resources

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

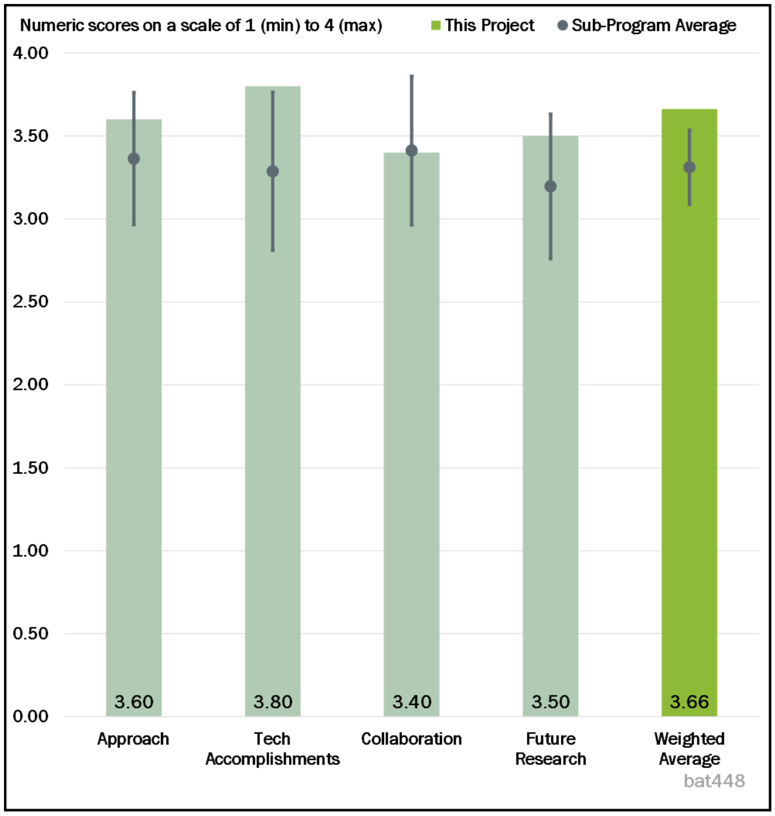

Figure 2-55 - Presentation Number: bat448 Presentation Title: Advanced Electrolyte Supporting 500 Wh/kg Lithium-Carbon/Nickel Manganese Cobalt (NMC) Batteries Principal Investigator: Chunsheng Wang (University of Maryland)

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 team has done excellent work in developing novel electrolytes that can form lithiophobic LiF-rich SEI on a Li- anode surface and Li-rich CEI on a Ni-rich NMC cathode surface. Developing all fluorinated electrolyte and lithiophilic substrates has been demonstrated to be effective in overcoming barriers for a Li-metal anode, such as low CE, Li-dendrite formation, and unstable cyclic performance. At the same time, this approach is also appropriate and effective to protect the surface of Ni-rich cathode materials. This project is well designed and planned, and the approaches adopted here address the key barriers of Li-anode and Ni-rich cathode materials.

Reviewer 2:

As a seedling project for Battery500, the PI and team have exceeded the expectation through outstanding work. First, there is the electrolyte-development plan using high concentrated electrolytes and additives for carbonate-based systems. The compositional approach to develop electrolytes capable of wide-temperature cycling is important. The team has also developed a feasible approach for making lithiophilic and lithiophobic substrates for uniform Li stripping and plating.

Reviewer 3:

The reviewer commented that the combination of lithiophilic substrate and lithiophobic LiF SEI to enhance the CE of a Li anode is innovative. The effectiveness of the design principle has been demonstrated by the recorded CE of more than 99.8% for Li anodes (highest CE for Li anode is 99.5%) at a high current of 0.5 mA/cm^2 and 1.0 mAh/cm^2.

For high-capacity electrodes (Li and Si anodes and $LiNiO_2$ and NMC811 cathodes) with a large volume change, the general electrolyte-design principle is to form SEI and CEI, which have weak bonding with active materials. This is critical for the success of high-energy Li-NMC811 cells and Li-$LiNiO_2$ cells.

Reviewer 4:

The PI focuses on addressing the interphase issue facing high-energy-density systems. The PI used two specific approaches. One is based on the correlation between interphase chemistry and electrolyte composition. The PI used various salt, solvent, and additives to form a LiF-rich SEI, which is known to be good for electrochemical cycling. The other approach is designing an interphase with lithiophilic substrate and a lithiophobic SEI on the Li anode to achieve high CE. The reviewer stated that these approaches are in line with the state-of-the-art understanding of the interphase and supported by theoretical and diagnostic characterizations.

Reviewer 5:

The PI proposed an effective approach for a more stable electrolyte for high-voltage cathodes by using salts that promote LiF in SEI and CEI and by using more stable fluorinated solvents. The PI did not list barriers that needed to be overcome. Even though the topic was electrolyte-centric, the PI presented results on high-Ni cathodes. Thus, it was unclear to the reviewer what the focus of this effort is.

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’s team has achieved tremendous success in meeting the milestone goals. This can be seen from both the high- profile publications and the excellent cycling performance of cells of practical relevance. More specifically, the PI has provided long cycle data for a Li anode, Si anode, Ni-rich cathode, and Li-rich cathode, all of which were tested under high-loading conditions.

Reviewer 2:

The reviewer remarked that Li plating and stripping on a bismuth (Bi)-graphite (G) substrate in 2.0 M $LiPF_6$-mixTHF electrolytes achieved 99.8% of CE, higher than 99.5% recorded CE for Li anodes at the same condition. Ionic-liquid electrolytes enable anode-free Cu-NMC622 to achieve more than 140 cycles at a capacity of 1.0 mAh/cm^2 (without pressure), which has not been achieved before. All fluorinated electrolytes with a LiDFOB additive enable $LiNiO_2$ to achieve a capacity of more than 250 mAh/g and a cycle life greater than 600, which the reviewer found highly impressive.

Reviewer 3:

The PI made significant accomplishments in improving the cyclic stability of the Li anode and Ni-rich cathode materials. The project milestones have been completed according to the project plan. The Li-plating and -stripping CE of 99.8% and full-cell CE of 99.9% are quite encouraging. The combination of lithiophilic substrates with lithiophobic LiF-rich SEI is also very interesting. These research results were published in top journals, such as *Nature Energy*, *Nature Nanotechnology*, and *Chem*.

Reviewer 4:

Discharge profiles of NCA||Li cells using 1.28 M LiFSI-FEC/FEMC-D2 electrolyte at different temperatures (-85°C to 70°C) look very promising. The reviewer would like to know if this has been tested on NMC811 cathodes.

All milestones and deliverables are completed way beyond expectation. Fluorinated and ionic-liquid electrolytes show promise for thick NMC cathodes. The LiF fluoride SEI and CEI help to achieve high CE for thick NMC cathodes.

The Mg-doped $LiNiO_2$ show good stability with no Co and good cycle life. The reviewer wondered what the areal capacity is or what the loading is of the cathodes that were tested.

The lithiophilic-lithiophobic surface modification of graphite and on Li-metal are new ideas. Has the PI thought of how these can be scaled up beyond proof-of-principle?

Reviewer 5:
This is a very high data-density poster. A lot of results were presented on various electrolytes, various high Ni nickelates, and 3-D lithiophilic hosts to mitigate interface. These results attested to the innovativeness of the PI.

However, it was difficult for the reviewer to assess the effectiveness of this work since supporting information on the cell parameters (e.g., N/P ratio) and testing parameters (e.g., rates, cut-off voltages) was not provided. It seemed that most of the results were based on coin cells with a low loading of 1-2 mAh/cm^2.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This project demonstrated wide collaboration with industry (Navitas Systems on solid-state batteries and Saft America) on the electrode and cell fabrication, with National Laboratories (PNNL and ANL) on electrolyte design and theoretical calculation and BNL on S and NMC cathode characterization.

Reviewer 2:
The reviewer said that the PI has collaborated with the industry, National Laboratories, and universities. The scope of collaboration work is broad, including electrode and cell fabrication, electrolyte component synthesis, material characterization, and theoretical calculation.

Reviewer 3:
Regarding this criterion, the PI has collaborated with two companies, three National Laboratories, and two universities on electrolyte and electrode design and validation.

Reviewer 4:
This is a seedling project. The reviewer did not know how much collaboration there is supposed to be. In any case, the progress has been extraordinary.

Reviewer 5:
The reviewer asserted that the PI did not provide any team details in the poster.

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 the proposed future research to be relevant to the overall project target and on the basis of current progress. The evaluation of Li-NMC811 and Li-$LiNiO_2$ pouch cells (areal capacity greater than 4.0 mAh/cm^2) using the PI's advanced electrolyte system is urgently needed in the context of meeting the Battery500 goal.

Reviewer 2:
The technical barriers were identified, and migration methods were proposed in the future work.

Reviewer 3:
This project will focus on developing a Li-C composite anode and testing performance of Li-$LiNiO_2$ and Li-NMC811 pouch full cells using all fluorinated electrolytes.

Reviewer 4:
The PI did not provide the percentage of completion on the project. However, based on the feasibility data, the reviewer suggested that the PI should down-select from the various promising electrolytes and demonstrate performance in a pouch cell with parameters (e.g., loading, N/P ratio, rate, g/Ah electrolyte) commensurate with achieving the 500 Wh/kg goal.

Reviewer 5:
From the poster, it was not clear to the reviewer if the project is continuing or completed.

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

Reviewer 1:
The reviewer found the technical accomplishments of this project to be exemplary. Many of the approaches can be followed to achieve high stability and cycle-life LIBs with energy density greater than 400 Wh/kg.

Reviewer 2:
This project, as a Battery500 seedling program, studies materials relevant to the Battery500 program (Li anode, Ni-rich cathode, Li-S cathode) at a scale of practical significance (large loading amount or large areal capacity).

Reviewer 3:
This project mainly focuses on developing an advanced electrolyte to support 500 Wh/kg Li-C/NMC batteries. As part of the Battery500 program, the reviewer asserted that this project highly supports the overall DOE objectives.

Reviewer 4:
Yes, this project aims to overcome the critical challenges of Li-metal anodes and Ni-rich cathodes, which are closely related to DOE goals.

Reviewer 5:
The work on electrolytes, high-Ni nickelates, and 3-D lithiophilic hosts is relevant 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:
According to the reviewer, the PI sufficiently achieved the stated milestones in a timely fashion using the resources for the project and collaborating with other partners, including companies and National Laboratories.

Reviewer 2:
The team and collaborators have strong capabilities and adequate resources for the proposed research.

Reviewer 3:
The resources for the project are sufficient to achieve the stated milestones in a timely fashion.

Reviewer 4:
The resources are adequate.

Reviewer 5:
The reviewer stated that no funding amount was provided.

Presentation Number: bat449
Presentation Title: Controlled Interfacial Phenomena for Extended Battery Life
Principal Investigator: Perla Balbuena (Texas A&M University)

Presenter

Perla Balbuena, Texas A&M University

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

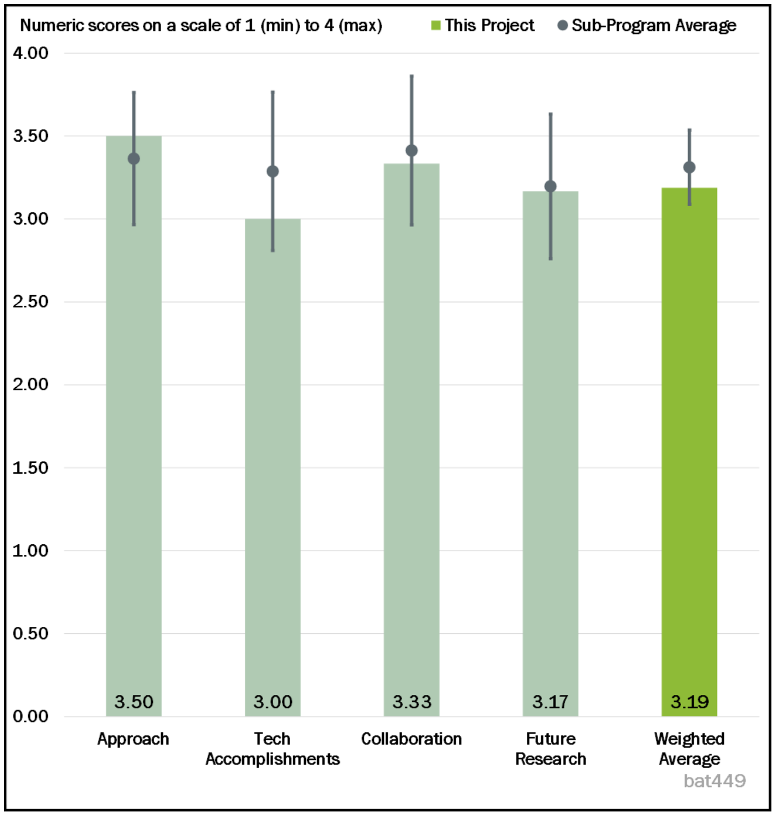

Figure 2-56 - Presentation Number: bat449 Presentation Title: Controlled Interfacial Phenomena for Extended Battery Life Principal Investigator: Perla Balbuena (Texas A&M University)

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:

Ab initio and classical molecular dynamics are powerful tools to investigate the structure and dynamics of electrolytes and the ion-transport mechanisms under an external electric field.

The reviewer said that collaboration with an experimental group at PNNL is important.

Reviewer 2:

The theoretical approach (e.g., ab initio and classical molecular dynamics) taken by the project team is very well designed to understand dilute, high-concentration, and localized high-concentration electrolyte decomposition at the electrode-electrolyte interface and the corresponding organic and inorganic structure of the SEI. The computational screening is expected to predict the optimum structure and formulation of novel electrolytes forming stable, uniform SEI with high Li-ion conductivity. Experimental synthesis and testing of theoretically predicted electrolytes in collaboration with PNNL will help to determine the validity of theoretical analysis and improve the theoretical model from experimental feedback.

The reviewer remarked that the system chosen by the project team is very appropriate for the current DOE project to solve the issue of performance degradation, such as uncontrolled growth of dendrites in Li-metal anodes and unstable SEI formation in Li-metal anodes and high-voltage cathodes.

Reviewer 3:

Application of density functional theory (DFT) simulations is expected to provide important details on reactivity in the concentrated and LHCEs and at the electrolyte-electrode interfaces. This is a suitable technique to complement experiments performed at PNNL; however, most of the presentation is dedicated to analysis of highest occupied molecular orbit (HOMO) and lowest unoccupied molecular orbit (LUMO) of solvent, salt, and diluent. The reviewer commented that this approach has been previously shown to produce erroneous predictions for battery electrolytes as discussed in "Electrochemical potential window of battery electrolytes: the HOMO–LUMO misconception". *Energy Environ. Sci.*, 2018,11, 2306-2309. Thus, most of the conclusions regarding reduction or oxidation of solvent, salt, or diluent are unreliable and likely do not correspond to the electrolyte reduction and oxidation at electrodes.

The micro-battery without an applied electric field shows very large deviation in the potential of bulk electrolyte that should lead to electrolyte decomposition that needs to be discussed and incorporated in a model.

Most of the motivation focuses on LHC electrolytes with TFEO diluent, but most of results are for bis(2,2,2-trifluoroethyl) ether with a 1,1,2,2-tetrafluoroethyl-2,2,3,3-tetrafluoropropyl ether (TTE) diluent. The reviewer stated that there is no conclusion regarding which diluent is better and why.

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 influence of an electric field (over-potential) on electrolyte reduction has been investigated and provided new and important insight into a reduction mechanism that has not been studied in this type of modeling before.

The HOMO-LUMO predictions of relative stability of electrolyte components were not correlated with experimental data and, according to previous work ("Electrochemical potential window of battery electrolytes: the HOMO–LUMO misconception". *Energy Environ. Sci.*, 2018,11, 2306-2309), do not provide realistic predictions of electrochemical stability of battery electrolytes. Simulations did not explain electrolyte stabilization.

For simulations of LHCE, the reviewer asked the project team to please compare predictions with experiments. No predictions of conductivity are given. It is important for the understanding of model accuracy.

Reviewer 2:
The modeling results can help explain the effectiveness of LHCE. But the reviewer found the modeling predictions to be rather incomplete. Specifically, the measurable properties of the SEI, such as the mechanical and transport (electronic and ionic) properties, are not modeled or predicted. As a result, it is difficult to compare modeling results with experiments.

Reviewer 3:
This theoretical study develops a detailed understanding of both structural and dynamic aspects of electrode-electrolyte interfaces in high-voltage cathode and Li-metal anodes using dilute, high concentration, and LHCEs. The Li-ion transport mechanism under an applied electric field has also been studied for LHCEs.

The PIs also carried out a preliminary investigation of SEI nucleation and growth, which can unravel the fundamental reaction pathways at the electrode-electrolyte interfaces of battery systems. This study will definitely help in designing new electrolytes and surface stabilization efforts of Li-metal anodes and high-voltage cathodes.

However, the reviewer asserted that no significant studies have been performed to understand the Li-ion diffusivity and migration within the organic and inorganic SEI layer, which are expected to be very important properties in understanding the dendrite formation of Li-metal anodes and performance degradation of high-voltage cathodes.

The PIs also mention the work in progress on machine learning and artificial intelligence (AI) for MD simulation, though no results have been presented.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The team at Texas A&M has an excellent collaboration in the National Laboratory (PNNL) network. The collaboration with the PNNL experimental group led by Dr. Jason Zhang, Dr. Jun Liu, and Dr. Jie Xiao on synthesis, testing, and prediction of SEI nucleation on Li metal will help to give feedback of experimental results on computational screening.

Reviewer 2:
There is good collaboration with PNNL with an experimental team providing electrolyte formulations and a modeling team providing HOMO-LUMO and electrolyte-structure predictions.

The reviewer asked the team to please show how modeling leads to new formulations that will be tested by PNNL and show improved properties.

Reviewer 3:
Collaborations with several researchers at PNNL should be enhanced by first modeling the mechanical and transport properties that can be measured and then experimentally testing key and specific predictions from the modeling effort, such as the SEI composition, mechanical, and transport properties.

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 efforts mainly focus on the further understanding of SEI nucleation and growth using impurities or defects as nucleation sites on Li-metal anodes. This study will be helpful in gaining a deep understanding of complex electrochemical processes occurring at the electrode-electrolyte interfaces. Future efforts to work with PNNL to establish clear connections between theory and modeling and electrolyte formulation could lead to the development of strategies mitigating the SEI formation. The future efforts for improved MD using machine learning and AI will definitely bring progress to the very demanding electrode-electrolyte interface modeling field.

Reviewer 2:
There is a good proposition to predict new formulations that will be experimentally tested; however, it was not clear to the reviewer how HOMO-LUMO calculations could be compared with characterization of SEI, CEI, and their properties.

Reviewer 3:
The reviewer asserted that the modeling effort should focus more on predicting the composition, structure, mechanical, and transport properties that can be experimentally measured. Close collaborations with experimentalists can also help specify and focus modeling activities. Specifically, the “defective sites” on “Li substrates” should be defined. “Effect of Li-metal thickness on battery performance” should be modeled by taking into consideration the mechanical behavior of electroplated Li and that of an externally applied pressure, as well as the SEI composition, structure, and mechanical and transport properties.

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

Reviewer 1:
According to the reviewer, the research project outcomes will lead to increasing the fundamental knowledge of electrode-electrolyte interface chemistry and the reactivity of Li-metal anodes and high-voltage cathodes using advanced modeling techniques. Experimental synthesis of the theoretically predicted electrolyte with controlled reactivity at the electrode-electrolyte interface may lead to Li-metal anodes and high-voltage cathodes for long cycle life and achieving the DOE targeted energy density without performance degradation.

Reviewer 2:
Modeling has a potential result in new electrolyte development ideas that will work with aggressive cathodes leading to improved energy density, if a correct modeling methodology is used.

Reviewer 3:
This reviewer observed high relevance.

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 adequate for the scope of the project.

Reviewer 2:
Sufficient resources are allocated.

Reviewer 3:
It was unclear to the reviewer how neural networks (NNs) are used since NNs are often treated as a black box that does not provide much insight.

Presentation Number: bat450
Presentation Title: Design, Processing, and Integration of Pouch-Format Cell for High-Energy Lithium-Sulfur Batteries
Principal Investigator: Mei Cai (General Motors)

Presenter

Mei Cai, General Motors

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

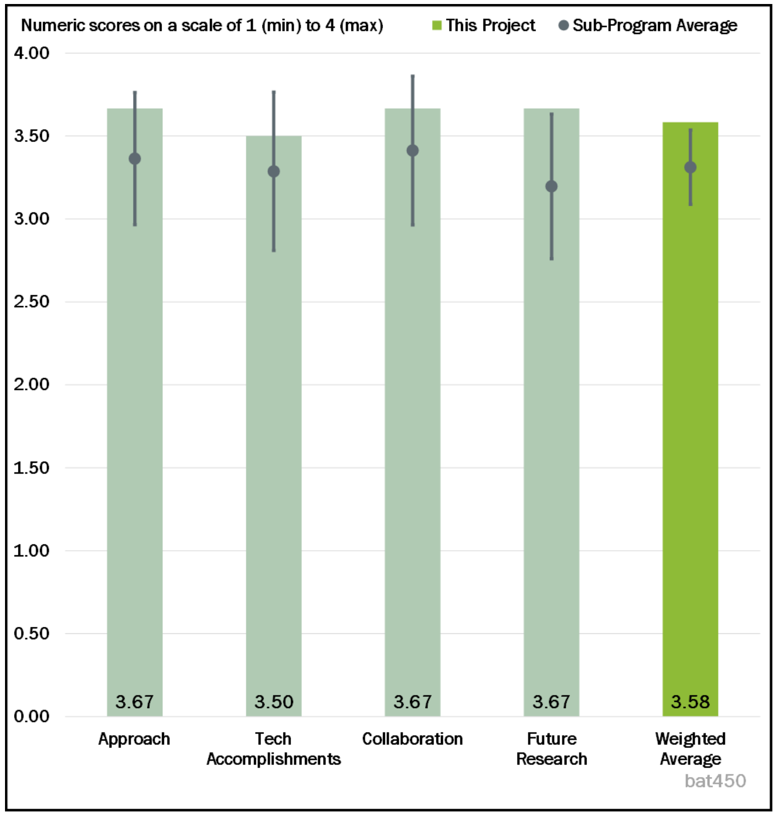

Figure 2-57 - Presentation Number: bat450 Presentation Title: Design, Processing, and Integration of Pouch-Format Cell for High-Energy Lithium-Sulfur Batteries Principal Investigator: Mei Cai (General Motors)

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 of investigating binder, additives for better adhesions, surface protection of the Li-metal surface, and electrolyte optimization targets the most critical problems of the Li-S battery. Coupling with pouch-cell fabrication, testing and modeling can yield an excellent understanding of effectiveness of the approach. The overall approach of materials discovery and characterization along with reconditioned testing is comprehensive and outstanding for Li-S battery research. The reviewer asserted that not many institutions are able to provide such a comprehensive approach to the problems. The capabilities of coatings and scale-up are helpful not only to this project, but also will be useful for others to collaborate with GM and testing their Li-S battery innovations.

There are challenges of performing Li-S research along with Li-ion research as S compounds are interfering with Li-ion chemistry. It was useful to the reviewer to know how GM separates and leverages the two activities.

Scale-up materials production and pouch-cell testing of Li-S are important even at this early stage. The limited scale- up effort GM is undertaking is really important to pinpoint the issues of materials and systems.

Reviewer 2:

This team has done excellent work in optimizing the S cathode and electrolyte for high-energy Li-S pouch cells. Approaches adopted by this team—such as optimizing the porosity of the S cathode, introducing new dual-phase electrolytes as well as developing a polysulfide trapping layer on the separator—are effective and produced impressive results in improving the overall performance of Li-S cell.

Reviewer 3:
This project is well designed with three approaches to overcoming the technical barriers, such as low S-loading and cycling life, as well as the polysulfide shuttle issue for Li-S batteries. The first approach is for S-cathode optimization including screening of binder and additive for better adhesion, surface treatment for better interface contact, roll-to-roll scale-up of the slurry-coating process, and cathode-porosity control by optimization of calendar process. The second approach is electrolyte optimization through the development of new, dual-phase electrolytes. The third approach deals with pouch-format cell design, fabrication, and test protocol including implementation of a polysulfide-interlayer and cell design with an internally developed software tool. The reviewer found that this project addresses these critical problems with very well-designed approaches.

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:
Excellent progress has been made toward the overall project. According to the reviewer, this project showed several technical accomplishments:

First, this project successfully designed and carried out a continuous S-electrode fabrication process using corona discharge for Al-surface treatment to improve the adhesion and a double-sided, flexible and rollable, crack-free electrode with high S-loading of 5 mg-S/cm^2.

Second, this project developed a polysulfide-trapping layer to improve cyclability of the S cathode, including the polypropylene (PP) separator coated with mixture of nano-oxide/C layer with a thickness of 10-16 µm and developed in-house a continuous coating process that can be easily scaled up for pouch-cell fabrication.

This reviewer saw these technical achievements and progress as outstanding against the performance indicators.

Reviewer 2:
The reviewer found the project progress to be excellent. In short period of time, the roll-to-roll (R2R) coater was built and tested. Scale up of S/C to kilogram scale was performed. The team also reported on the dual-phase electrolyte for Li-S battery. This is an interesting concept, and the reviewer would like to see more information and results related to this effort.

Reviewer 3:
The reviewer commented that this project has made remarkable progress in addressing the critical challenges of high-energy Li-S pouch cells. Coulombic efficiency and cyclic performance of Li-S cells were significantly improved by optimizing the S cathode and developing new, dual-phase electrolytes. Remaining challenges—such as further increasing the S loading, reducing the porosity of the cathode, and improving the Li-anode CE—are also identified in this project.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The PI of this project has excellent collaborations with the research groups led by Dr. Jun Liu and Dr. Jie Xiao at PNNL

Reviewer 2:
It is mainly a GM team with collaboration from PNNL. As this is a Battery500 seedling project led by PNNL, the collaboration is expected. PNNL has done quite a lot of the Li-S battery developments in the past. The collaboration helps to speed up the development process at GM.

Reviewer 3:
According to the reviewer, this project has a very good team and good collaborations with PNNL.

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 plans are clearly identified, according to the reviewer. This project will focus on optimizing the cathode-fabrication process to improve S utilization as well as developing solid or liquid electrolytes to enhance cyclic stability.

Reviewer 2:
The reviewer remarked that this project has planned its future work well along with the milestones for the remaining time of this project.

Reviewer 3:
The proposed future work is focused on improving the R2R coating to increase loading and improving the electrolyte. These are important directions for this project.

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

Reviewer 1:
Yes, this project aims to overcome the critical challenges of Li-S batteries, which are highly relevant to DOE goals.

Reviewer 2:
This project is very relevant to DOE’s objective in energy storage: high energy, long lifetime, low cost, and using earth-abundant materials.

Reviewer 3:
This project is relevant and supportive of DOE objectives to develop an affordable, high-energy-density battery for electric vehicles. There is still a challenge to achieve Li-S batteries with long cycle life and good rate capability. The reviewer remarked that this project is well designed to address such challenges.

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 for the work performed and planned.

Reviewer 2:
Current resources for this project are sufficient to achieve the project goals.

Reviewer 3:
The resources of this project are sufficient to achieve the milestones on time.

Presentation Number: bat451
Presentation Title: Solvent-Free and Non-Sintered 500 Wh/kg All Solid-State Battery
Principal Investigator: Mike Wixom (Navitas Advanced Solutions Group)

Presenter

Binsong Li, Navitas Advanced Solutions Group

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

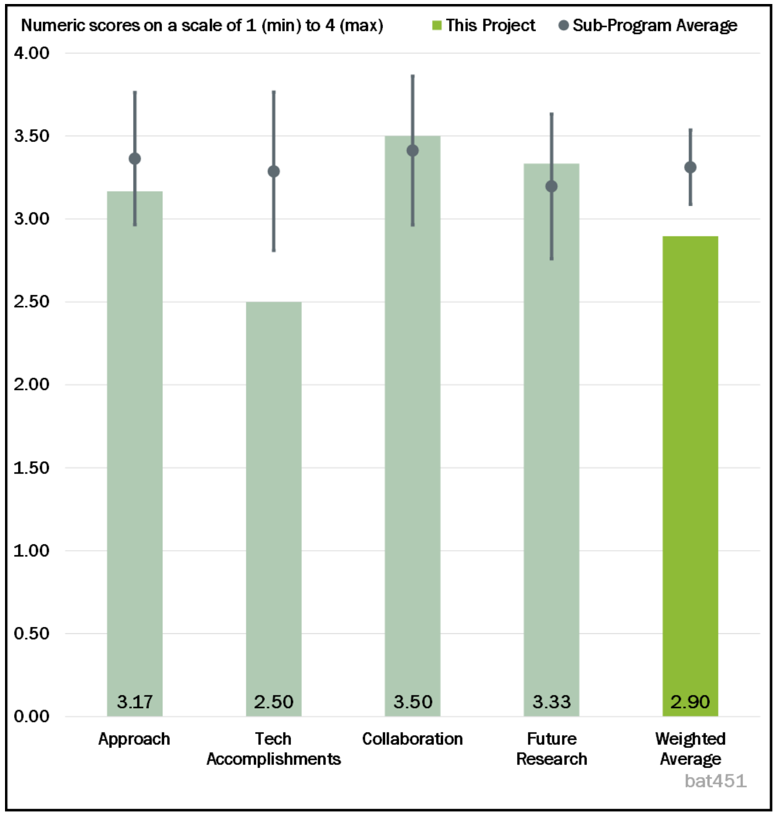

Figure 2-58 - Presentation Number: bat451 Presentation Title: Solvent-Free and Non-Sintered 500 Wh/kg All Solid-State Battery Principal Investigator: Mike Wixom (Navitas Advanced Solutions Group)

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 team plans to tackle key issues associated with solid-state electrolyte (SSE) batteries from critical current density, cathode stabilization, and SSE stabilization to make them less air sensitive and prevent degradation for sufficiently long time needed for the roll-to-roll process, single-step lamination, and multi-layer stack assembly.

The reviewer indicated that the demonstrated air stability for 300 min. is an important achievement together with the initial stabilization of the lithium cobalt oxide (LCO) cathode, which increased capacity by almost a factor of two compared to an untreated electrolyte-electrode.

Testing of the currently assembled Li | treated SSE | treated NMC pouch cell will provide critical evaluation of the proposed approach. The reviewer remarked that preliminary results on the Li metal and Li |SSE | Li_2S indicate that it will be quite challenging to achieve 500 Wh/kg at room temperature for 1,000 cycles.

Reviewer 2:

The Li metal, S electrolytes, and high-energy cathodes are extremely relevant, but the reviewer was unconvinced that scaling up the manufacturing processes is relevant when Slide 6 shows a 25% capacity loss in three cycles.

Reviewer 3:
A summary of the Phase 1 effort would have been helpful to the reviewer for context in reviewing Phase 2, especially since the project has not been previously reviewed (per Slide 11 in version 2).

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 impressive progress has been reported toward stabilization of SSE in air and stabilization of the Li metal—SSE and treated LCO cathode—electrolyte interfaces via the interphase formation. It resulted in doubling of the LCO-cathode capacity and improved critical current densities for Li metal—electrolyte symmetric cells.

The best results are shown for the LCO cathode, while the most relevant to achieving 500 Wh/kg goals—NMC811 films with high loading—were prepared but have not been characterized. But it was not clear to the reviewer why electrolyte stability of NMC811 has been also achieved or not during cycling along with minimization of interfacial impedance for thick NMC811 **-** electrolyte. Results are lacking for the April milestone with 3 mAh/cm^2 loading of NMC811.

Reviewer 2:
This project has been operating for about 2 years and shows just three cycles of data on Slide 6. This seemed to the reviewer to be a very slow progress. No other progress, such as on stabilizing the Li-metal interface and enhancing the S-electrolyte air stability, is shown in any detail.

Reviewer 3:
Limited cell-cycle and performance data are shown to illustrate steps in development (i.e., Swagelok cell performance --> coin cell --> disk-in-pouch --> pouch). The reviewer understood that the focus has been on air stability and electrode-process development, but it would also have been helpful to see how these steps translate into performance, support, and understanding of technology potential along the pathway.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Collaboration between the University of Maryland, a National Laboratory, and Navitas seemed excellent to the reviewer with all parties contributing critical solutions for the problem.

Reviewer 2:
There was good communication among the collaborators and their contribution.

Reviewer 3:
The reviewer had 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 stated that the future work is excellent, and hopefully the team can execute on it.

Reviewer 2:
While the proposed plan is feasible, it was not clear to the reviewer what the team will do if the April 2020 milestone on cycling high-loading NMC811 cathode **-** Li metal shows fast degradation at room temperature. It is not clear what the mitigation strategy is for achieving 500 Wh/kg. The presented results for Li_2S | SSE | Li do not indicate that this approach will lead to 1,000 cycles with 500 Wh/kg at room temperature.

Reviewer 3:
Proposed research seemed appropriate to the reviewer, who requested cell-performance data to benchmark performance accomplishments in both developed processes and cell technology.

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

Reviewer 1:
The project addresses key technical barriers for mass production of the high-energy-density batteries with NMC811 and Li_2S cathodes and Li metal via materials and process development. If successful, these batteries have a potential to be used in transportation and energy storage applications.

Reviewer 2:
Yes, this project supports the DOE objectives to develop high Wh/g technologies.

Reviewer 3:
The Li-metal, S electrolytes, and high-energy cathodes are extremely relevant, but the reviewer was unconvinced that scaling up manufacturing processes is relevant when Slide 6 shows a 25% capacity loss in three cycles.

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

Reviewer 1:
It is a large project with a good combination of industrial, academic, and National Laboratory expertise, allowing the team to efficiently tackle challenging issues.

Reviewer 2:
Resources seemed sufficient to the reviewer to support the outlined research.

Reviewer 3:
There are appropriate resources for such an effort.

Presentation Number: bat452
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 four reviewers evaluated this project.

Project Relevance and Resources

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

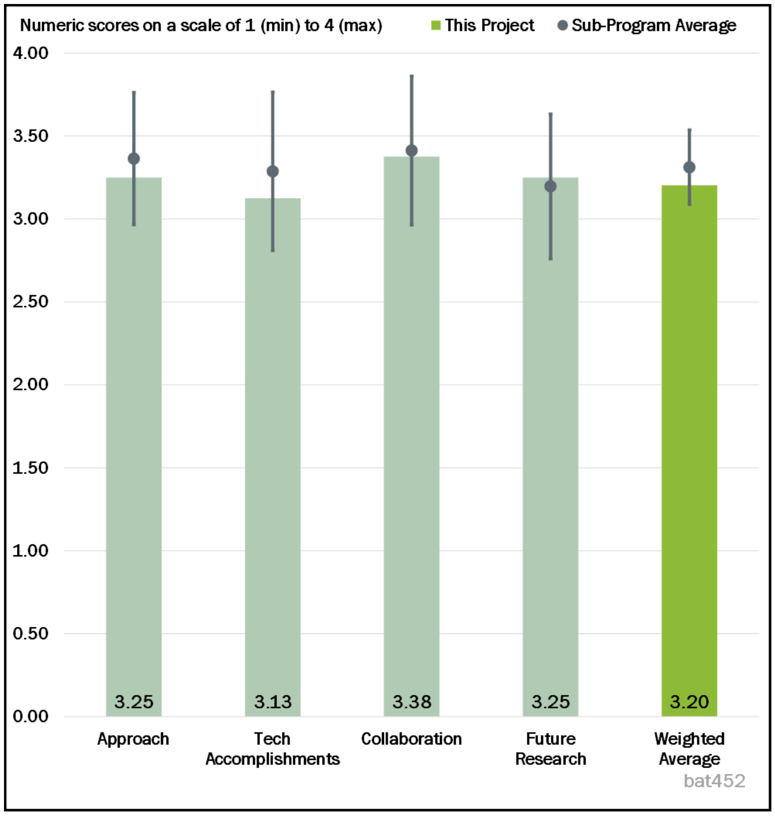

Figure 2-59 - Presentation Number: bat452 Presentation Title: High-Energy Solid-State Lithium Batteries with Organic Cathode Materials Principal Investigator: Yan Yao (University of Houston)

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 the approach used to investigate multi-electron, organic battery-electrode materials to be feasible and the plan is good. The focus this year has appropriately been on a major challenge confronting these types of systems—a low, active-material ratio (20 wt. %) in the cathode composition. The goal is to increase this to 60 wt. %. This will be necessary in order to meet the project-specific energy requirements.

Reviewer 2:

This project is well designed with approaches to overcome the technical barriers for solid-state Li batteries. This project designed a strategy of using a solution-assisted mixing method to form electrolyte-coated, organic insertion material (OIM), cathode-core shell structures that could be later compacted into an ideal microstructure. The reviewer found this project addresses the critical problems with well-designed approaches.

Reviewer 3:

The work certainly demonstrates the challenges faced by materials science in developing future battery materials.

Reviewer 4:

The PI proposed a solid-state battery technology by integrating multi-electron, OIMs, and sulfide-based solid electrolytes. According to the reviewer, the technical approach possesses high potential toward a low-cost, green, and high-energy battery technology. However, many significant barriers need to be addressed in future research: low theoretical capacity and voltage of organic cathodes, low-materials-utilization rate at high loading or high materials content, Li -instability for long-term cycling, and low cell-rate capability as a result of poor kinetics of both OIM materials and OIM/SEI.

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:
Excellent progress has been made in the overall project, which the reviewer noted showed several technical accomplishments:

- This project successfully developed a solution process (SP) that drastically modified the microstructure, leading to homogeneous mixing of a pyrene-4,5,9,10-tetraone (PTO) cathode and a Li_6PS_5Cl solid electrolyte.
- Using the solution process, at 40 wt. % of active material ratio in the cathode composite, the material utilization increased from 49% (for the dry process) to 88% for the solution process.
- The improved material utilization is reflected at higher areal capacity, which is doubled compared to the dry process (at 40% PTO fraction).
- The cathode shows 75% retention for 100 cycles.
- An optimized solution process triples areal capacity to over 1.0 mAh/cm^2 and 87% capacity retention for 35 cycles.

These achievements are quite impressive for reaching the overall goals of this project. This reviewer saw these technical achievements and progress as excellent against performance indicators.

Reviewer 2:
The team made considerable progress toward improving the active material ratio and areal capacity by developing a solution-assisted mixing method this year. The team has already increased the active material ratio in the cathode composition from 20 wt. % to 40 wt. %. The reviewer commented that the study would benefit from a more in-depth analysis of the effect of discharge rate and shelf life on cell capacity.

Reviewer 3:
According to the reviewer, the project team achieved excellent technical accomplishments during this review period. The project team has been focusing on improving the active materials utilization rate and electrode areal capacity through the detailed studies of material improvement, cathode-electrolyte interface reactions, and effective materials processing. That technical progress also benefits other research in the battery community.

One thing that PI may evaluate is the relevance of the focused materials toward the final energy target. The PI may have a big picture in mind. The reviewer wanted to know what the possible pathways are toward the final performance targets and what the applicable materials are to fulfill such requirements.

Reviewer 4:
The project has accomplished much in terms of milestones. The project is on track and in good shape.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that the PI of this project has excellent collaborations with many research groups in this field.

Reviewer 2:
The project has very good collaboration. The team has been working well together and accomplished great things.

Reviewer 3:
The PI has close collaboration and coordination with universities and National Laboratory partners for materials development and characterization. The PI showed collaborative work on the polyimide membrane and cross-linked polymer electrolyte. The reviewer inquired if those membranes or electrolytes were adopted in the cell test.

Reviewer 4:
There is some collaboration with members of the Battery500 Consortium team members (PNNL and BNL). The reviewer suggested that the effort would be strengthened with greater interaction with other research 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 proposed future plans are well focused. The team will continue to optimize the cathode-fabrication process to increase the active material ratio from 40 to 60 wt. %. Attempts will be made to increase rate capability by reducing the solid-electrolyte thickness.

Reviewer 2:
This project has planned its future work and milestones for the remaining time of this project well. However, the reviewer suggested that more technical details need to be developed for the future plan.

Reviewer 3:
The proposed future research is consistent; however, the reviewer remarked that the team needs more detail.

Reviewer 4:
According to the reviewer, the PI is aware of the significant challenges that still remain to get high energy and stable cycle life of the solid batteries and proposed reasonable future efforts. To reach or approach the target cell energy, new OIMs with higher capacity and voltage are essential and would be the focus of the future research. To tackle the sluggish kinetics of both the active materials and OIM/SEI, stable and highly conductive solid electrolytes should be identified to support the cell-level integration. Although Li-anode stability is a key to long-term cell cycling, it may be addressed through collaboration with other BMR teams and would not be the focus of the project.

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

Reviewer 1:
The reviewed noted that an all solid-state battery built on OIMs provides high potential for the next generation of low-cost and high-energy battery technology, which supports DOE's objective. Again, OIMs with higher capacity and voltage are the key to the success of the effort.

Reviewer 2:
The project is highly relevant to DOE's objectives and, if successful, would eliminate the use of Co that is predicted to have future supply constraints. A solid-state battery would minimize safety issues by eliminating flammable and volatile electrolytes.

Reviewer 3:
This project is relevant and supportive of DOE objectives to develop an affordable, high-energy-density battery for electric vehicles. The reviewer commented that there is still a challenge to achieve all solid-state batteries with long cycle life and good rate capability. This project is trying to address such challenges.

Reviewer 4:
This project is relevance to the DOE objective because the works develops improved materials and systems for high-energy 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 stated that the project showed sufficient resources to achieve the stated milestones. The project team has accomplished good things with their resources.

Reviewer 2:
The resources appear to be adequate for completing the tasks within the time frame.

Reviewer 3:
According to the reviewer, the resources of this project are sufficient to achieve the milestones on time.

Reviewer 4:
The resources are appropriate for the scope of the project.

Presentation Number: bat453
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 three reviewers evaluated this project.

Project Relevance and Resources

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

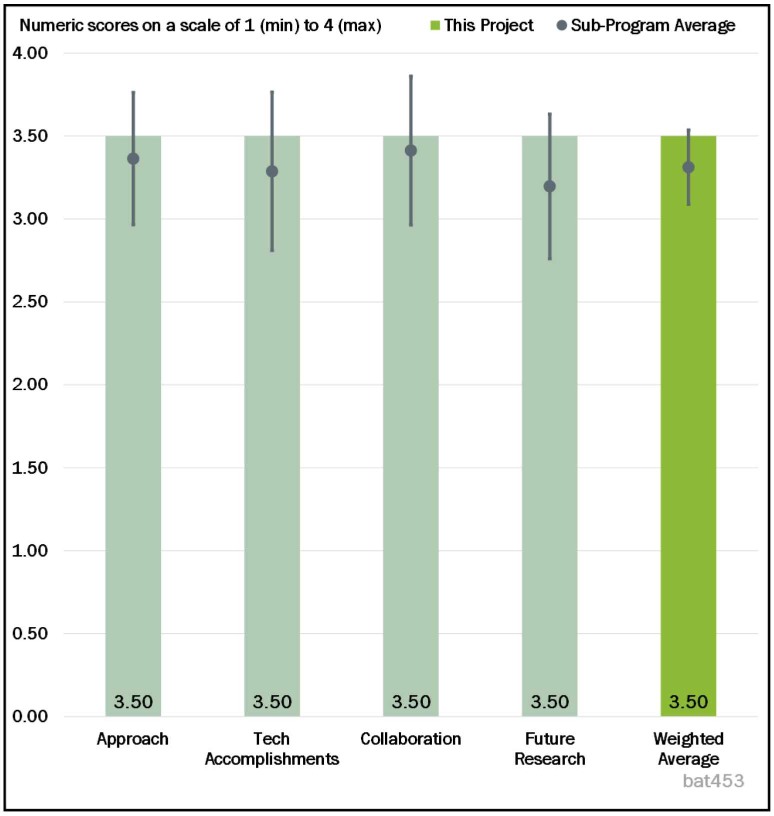

Figure 2-60 - Presentation Number: bat453 Presentation Title: Composite Cathode Architectures Made by Freeze-Casting for All Solid-State Lithium Batteries Principal Investigator: Marca Doeff

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, the PI and team have shown the feasibility of a full solid-state battery that can undergo cycling without a liquid electrolyte. The bi-layer and tri-layer garnet structure provides a scaffold for filling cathodes. Lower cell impedance occurs when a plastic solid electrolyte is filled in the pores of the LLZO-NMC cathode structure. The freeze-casting method can be optimized to maximize active material and performance. Combining the tape with the freeze-casting method provides an excellent approach overall toward fabrication of solid-state batteries.

Reviewer 2:

The approach for fabricating a porous electrode with connected channels using freeze-tape casting is very innovative for solid-state LLZO Li batteries. However, the reviewer stated that how to reduce the interface resistance between LLZO and the cathode active materials, especially after cycles, still needs to be addressed.

Reviewer 3:

The research approach seems well designed to understand cathode properties to enable the construction of a high- energy-density battery.

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 team communicated a clear path for addressing and developing an understanding of the challenges around the LLZO framework to enable high energy-density cells.

Reviewer 2:
There is good control of density and thickness using the tape-cast method for producing thin LLZO structures. Porosity of LLZO layers can be varied using freeze-cast methods. The PI has developed a slurry method for incorporating NMC in the porous LLZO layer. The reviewer wondered about the filling fraction of the cathode either by weight or volume percentage. Overall energy density will be affected by the porous LLZO template. What was the weight fraction of the active cathode material versus the tri-layer template? Significant reduction of cell impedance occurred after incorporating plastic electrolyte—from 180 ohm/cm^2 to 350 ohm/cm^2. The reviewer wondered about the composition of the soft electrolyte.

Reviewer 3:
A porous LLZO layer with controlled pores was fabricated on a dense LLZO layer. The reviewer noted that it is still hard to fill all the pores with solid active materials. The contact between LLZO and active materials are hard to maintain during cycles. The cycle life and energy density of the cell need to be addressed. The three-layer structure cells are more suitable for liquid electrodes.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This is a collaborative project with Montana State University and Mercedes Benz.

Reviewer 2:
Dr. Doeff's team has collaborated with Montana State University and Mercedes Benz R&D North America.

Reviewer 3:
The reviewer remarked that the team expertise is clearly articulated and contributes to the research.

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 research pathway seemed to the reviewer to be targeted toward the ultimate goal of a solid-state cell build.

Reviewer 2:
Optimization of the pore size and cathode particle size can increase the overall loading. The reviewer wondered if a theory and modeling effort can help to determine the pore size, geometry, and volume fraction of the active material, etc.

Reviewer 3:
The team proposed to develop methods to fill most of the LLZO-scaffold pore space. The reviewer commented that how to maintain the good contact between the LLZO scaffold and solid active materials during cycles is still a challenge.

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

Reviewer 1:
The reviewer stated that the project supports the Battery500 goal toward achieving 500 Wh/kg. The tasks support stabilizing the Li-metal and cathode architectures using the porous framework.

Reviewer 2:
The project fully supports the overall DOE objective of developing high-energy, low-cost, and safe batteries.

Reviewer 3:
Yes, this project advances technology toward high energy-density battery technologies.

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

Reviewer 1:
LBNL has sufficient resources for the project to achieve the goal and milestones.

Reviewer 2:
Funding level seemed adequate to the reviewer for the planned research.

Reviewer 3:
Resources are adequate.

Presentation Number: bat454
Presentation Title: Development of Long-Life Lithium/Sulfur-Containing Polyacrylonitrile Cells
Principal Investigator: Ping Liu (University of California at San Diego)

Presenter

Ping Liu, University of California at San Diego

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

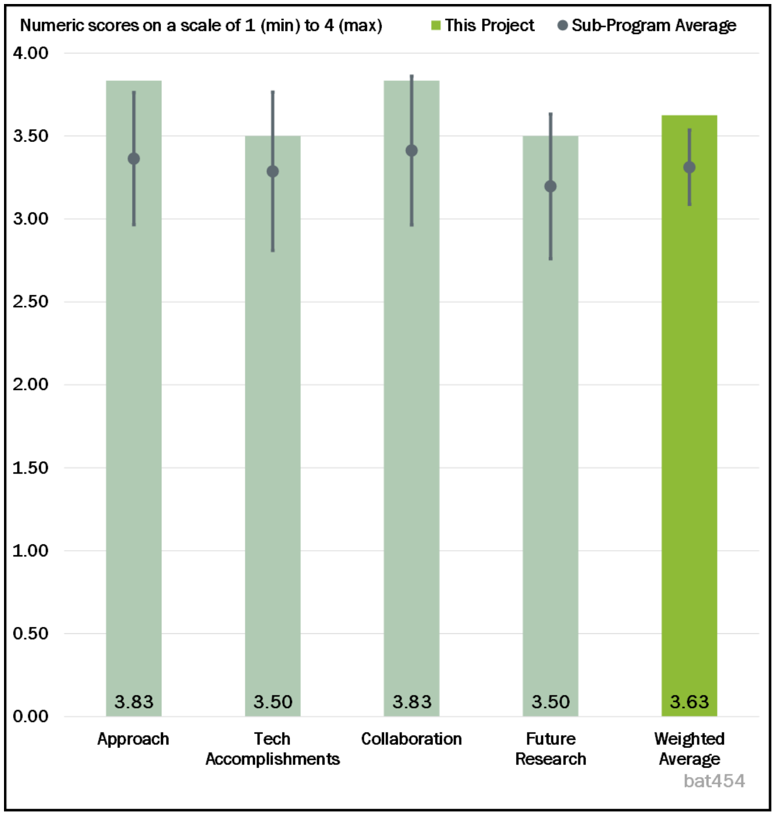

Figure 2-61 - Presentation Number: bat454 Presentation Title: Development of Long-Life Lithium/Sulfur-Containing Polyacrylonitrile Cells Principal Investigator: Ping Liu (University of California at San Diego)

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 is a Keystone 2 project of the Battery500 Consortium focusing on electrode architecture of both anode and cathode. At the anode side, the work performed includes Li-metal protections and 3-D anode structures. Both approaches are focused on stabilizing the Li-metal surface and achieving uniform Li deposition. Several PIs of various institutions are part of this Keystone 2 project and have made significant progress. The anode work is highlighted in this presentation but is not discussed in detail.

The cathode work is focused on S and polymer-composite materials. In particular, sulfur and polyacrylonitrile are co-sintered to form a S-rich composite material. This composite can be potentially electronically conductive when doped to overcome the low electric conductivity of S materials. Elemental S is also covalently bonded with the carbon network to anchor the S to the cathode network structure to prevent polysulfide dissolution. The sulfurized polyacrylonitrile (SPAN) composite is a very effective approach to overcome the issues of the S electrode. Although this and similar approaches have been reported in the literature over the years, a systemic study has never been done to fully understand and quantify the approach. The current experimental work in combination with theoretical modeling is excellent to move the technology forward.

Another overlooked area in Li-S battery research is the Li-metal electrode and compatible electrolyte with both SPAN and Li metal.

Reviewer 2:
The approach of the research supported the overall Battery500 goals. SPAN and NCM811 with metallic Li could achieve the program goals. It appeared to the reviewer that the shuttle effect was reduced.

Reviewer 3:
The approach, such as the focus on S cathodes, is very good as the reviewer indicated like the NMC811 and higher Ni cathode R&D is reaching diminishing returns.

Regarding Slide 8, the reviewer stated that this was basically Seeo's construction, and the company found dendrite issues eventually.

Regarding Slide 4, the reviewer said that the 2 V, open-circuit voltage (OCV) of the S couple makes high energy challenging. This project's goal of 300-350 Wh/kg looked concerning to the reviewer, considering where the Li metal/NMC cell currently is. Hopefully, there is a clear path to reaching 500 Wh/kg.

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 made significant progress on Li-metal protection and 3-D Li deposition. Multiple methods of Li-metal protection are developed within the team, such as polymer-based surface protection, solid-state electrolyte, and electrode additives. These approaches have generated high efficiency and long cycle life for Li-metal deposition during testing in their own institutions. At the S cathode side, the team has developed a Li-metal, compatible electrolyte system for the SPAN cathode. This is an outstanding solution to a long-existing problem for the SPAN- based Li-sulfur battery.

Reviewer 2:
The progress of the project meets the program expectations and all the milestones were achieved.

The reviewer had a question and a comment:

During the discharge of SPAN, does any S become dissolved?

The rate of the cells in the new electrolyte with SPAN should be described next time.

Reviewer 3:
Again, Slide 10 shows 99.37% CE, which means that twice the amount of Li is gone in 150 cycles. Subsequently, this needs to be increased substantially. The reviewer indicated that it should not be necessary to cycle a cell 900 times to determine that the CE is too low to be commercially viable.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This is an outstanding team with a prominent scientist, such as Goodenough; a strong team lead, Liu; and both established and fledging scientists. The team includes both experimental and theoretical (Texas A&M) aspects of the work with strong testing and diagnostics efforts (BNL).

Reviewer 2:
The reviewer found the collaboration and coordination across the project team to be nicely integrated.

Reviewer 3:
The PI demonstrated the collaboration across Battery500 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 noted that the team has proposed several different fronts for future work. This is well justified since multiple PIs will be involved in the Keystone 2 project.

Understanding 3-D electrodes in a pouch cell is important as the new approaches need to be verified in a realistic setting. Performing simple-system modeling before the pouch cell work can provide a better understanding of the approaches. In fact, most of the Li-metal protecting work and approaches will need to be tested in a standard cell setting and in a more controlled and comparable environment. The simple-system modeling in Slide 17 is a particularly good approach that compares different compositions and chemistries. This really shows the advantages and limitation of SPAN and where the S electrode research needs to be focused.

Reviewer 2:
The PI provided the high-level description of the future work. This is logical to achieve the overall program goals.

The reviewer stressed that the PI should provide more details so the barriers to the realization can be better accessed.

Reviewer 3:
The S cathode work is more than difficult enough; the reviewer would not have this team worried about 3-D Li anodes (see Slide 18).

This comment is not directed at Professor Liu, but the reviewer thought that the Battery500 program would benefit from additional cathode R&D beyond or instead of the high Ni NMC. That work is likely reaching diminishing returns, and S is extremely difficult (but very worth pursuing).

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

Reviewer 1:
The Keystone 2 project is geared well with the DOE-VTO objectives of developing high energy-density and long cycle- life batteries. Li-metal anodes have promise to enable very high-energy-density rechargeable batteries. The key challenges are Li dendrites and un-uniform deposition. A major part of the work is focusing on addressing both issues and is making outstanding progress. The SPAN electrode work is particularly supportive of DOE’s mission to use earth-abundant materials for large-scale energy storage deployment. The SPAN materials only contain S, C and N, making it a very attractive materials for large-scale deployment.

The reviewer observed that one has to put this progress into prospective and understand that Li dendrites and S electrodes have been very challenging issues for the science community for the past half a century.

Reviewer 2:
Research on S or NMC811 cathode and metallic Li anode is definitely relevant to DOE goals.

Reviewer 3:
The reviewer said that this project is highly relevant.

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 there are appropriate resources.

Reviewer 2:
The team seems to have sufficient resources for the work reported. However, it was hard for the reviewer to judge. There is only a lump sum amount of funding for the entire Battery500 project in the Overview slide. It is not clear how much support there is for each sub-team and task.

Reviewer 3:
The PI has adequate resources for the proposed research.

Presentation Number: bat455
Presentation Title: In Operando Characterization of Lithium Plating and Stripping
Principal Investigator: William Chueh (Stanford University)

Presenter

William Chueh, Stanford University

Reviewer Sample Size

A total of three reviewers evaluated this project.

Project Relevance and Resources

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

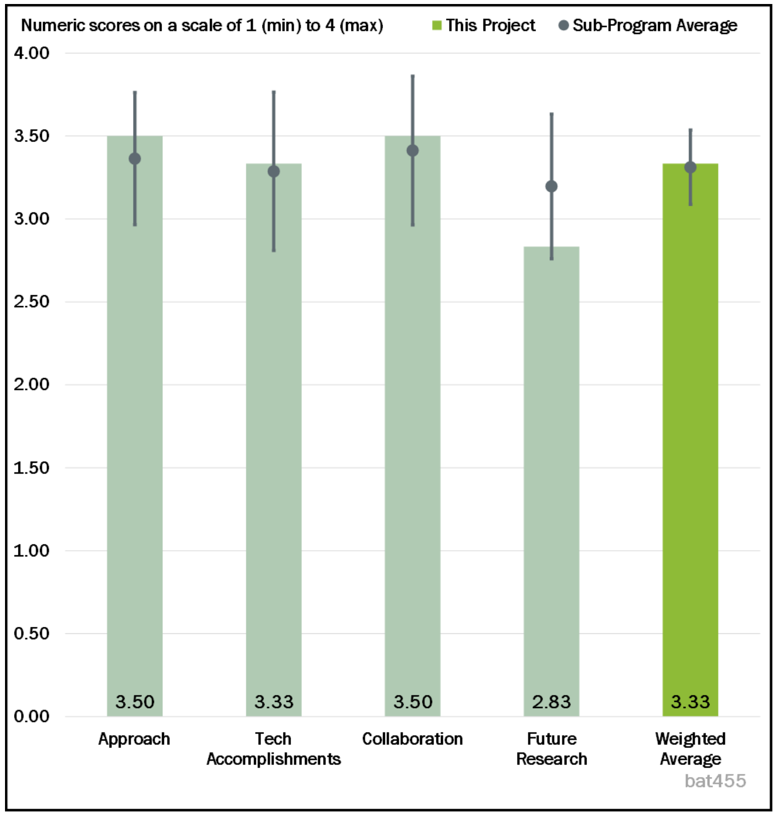

Figure 2-62 - Presentation Number: bat455 Presentation Title: In Operando Characterization of Lithium Plating and Stripping Principal Investigator: William Chueh (Stanford University)

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 aims to develop operando diagnostics tools to monitor Li plating and stripping and provide guidance on electrolytes, additives, and cycling procedures for developing Li-metal based batteries. The reviewer indicated that this is an excellent approach that directly addresses the need to achieve the overall goals in the Battery500 program.

Reviewer 2:

The approach of this project is to develop in situ spectroscopic techniques to understand morphology evolution and CE trends in Li-metal stripping and plating in liquid electrolytes. A few key questions are clearly outlined, and the techniques developed are used to answer them.

Reviewer 3:

The main challenge of the Battery500 project is the stability of the Li-metal electrode. This project strives to quantify the Li electrode during operation.

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 milestones are completed or on track. There were numerous presentations given by the PIs although no publications yet (the reviewer imagined that a few are on the way in FY 2020 given the well-developed nature of the data sets presented).

The in situ XRD work is very nice and clearly shows the reactivity problem of Li-metal in carbonate solvents. The reviewer was surprised at how important open-circuit corrosion of Li is in this solvent system and was pleased with the clarity about how these results show this to be a problem. The addition of HF to manipulate the Li- metal deposition morphology is also a nice outcome. Grazing-incidence small angle X-ray scattering (GISAXS) and atomic force microscopy (AFM) are currently being developed to further understand the morphology and nucleation during Li-metal plating.

Reviewer 2:
The reviewer stated that very good progress was made in this project. Studies using three operandi diagnostics tools were presented: XRD, GISAXS, and AFM.

Operando XRD was used to quantitatively probe Li plating and stripping and track the amount of Li on the surface. Because XRD of Li (110) was used as the sole marker, the detection limit as well as the accuracy and sensitivity of this technique should be considered. Li plating in real battery cells is known to take various forms and crystalline orientations, which may present challenges in using this technique.

GISAXS was used to monitor periodic structure during Li deposition. While the study on an electrolyte pseudo-model system involving HF is very interesting, the reviewer wondered whether this may be system specific. How applicable is this technique to the real systems outside of the model?

Reviewer 3:
Quantifying Li deposition with X-rays is a challenge. This effort seems to make these measurements about as well as the reviewer had seen. Information on morphology and microstructure is also supplied. Another study in this program suggests that some deposited Li can be non-crystalline. This is not accounted for in this study. Nevertheless, the presentation was informative.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
Collaboration across the team in the Battery500 program is excellent. There was also a good use of the DOE user facilities.

Reviewer 2:
The reviewer was impressed with all Battery500 collaborations, including this one although not too much presented outside the two PI's National Laboratories. There is still a strong collaboration between the two.

Reviewer 3:
Some collaboration is listed, but close collaboration is not apparent. The studies seem fairly independent.

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:
Overall, the proposed future work is logical toward addressing the barriers in Li-metal based batteries.

Considering that Li plating and striping in a liquid electrolyte have been studied for decades, it would be useful to build and examine additional model systems based on the knowledge existing in the literature. The reviewer would also like to have seen some demonstration on using the techniques in real battery cells under realistic cycling conditions. In the end, it will be important for such diagnostic studies performed on cells over a large number of cycles.

Reviewer 2:
Proposed future work is a reasonable extension of current work although only briefly mentioned.

Reviewer 3:
The reviewer observed that continuing the present effort is proposed, with few details. No possible solutions are proposed.

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

Reviewer 1:
The use of a Li-metal anode is an important step toward achieving the Battery500 goals. Current technology faces significant challenges in terms of low CE of Li plating and striping. This project supports the overall DOE objectives, and it is very relevant.

Reviewer 2:
The reviewer commented that the PI attacks the main challenge for the program. If successful, this would reduce the cost of batteries.

Reviewer 3:
Enabling Li-metal electrodes is a key goal for DOE-VTO, and this project entirely aligns with that mission.

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

Reviewer 1:
It was unclear to the reviewer how much funding this project received, so it was difficult to judge whether or not enough resources are available. However, the overall Battery500 program has sufficient resources.

Reviewer 2:
The PI seems to have sufficient funds to conduct the studies.

Reviewer 3:
The project appears sufficiently supported although the total direct funding from the Battery500 to this project is not provided.

Acronyms and Abbreviations

°C	Degrees Celsius
μL	Microliter
3-D	Three-dimensional
AFM	Atomic force microscopy
Ah	Ampere-hour (amp-hour)
AI	Artificial intelligence
Al	Aluminum
Al_2O_3	Aluminum oxide (alumina)
ALD	Atomic-layer deposition
ALS	Advanced Light Source
ANL	Argonne National Laboratory
Bi	Bismuth
BMR	Battery Materials Research Program
BNL	Brookhaven National Laboratory
C	Carbon
CAM	Cathode active material
CB	Cell build
CC	Constant current
CEI	Cathode-electrolyte interphase
CE	Coulombic efficiency
CFM	Composite framework materials
CLi-P-SCP	Conjugated Li-polymer S- containing polymer
cm	Centimeter
CNT	Carbon nanotube
Co	Cobalt
CO_2	Carbon dioxide
COTS	Commercial off-the-shelf
CT	Computerized tomography

DCIR	Direct current internal resistance
DCR	Discharge capacity rate
DEMS	Differential electrochemical mass spectroscopy
DOE	Department of Energy
DRX	Cation-disordered rock salt
DST	Dynamic stress test
EAM	Electrochemically active monolayer
EC	Electrochemical (electronic) conducting
EDS	Energy-dispersive X-ray spectroscopy
EELS	Electron energy loss spectroscopy
EERE	Energy Efficiency and Renewable Energy
EIS	Electrochemical impedance spectroscopy
EM	Electron microscopy
EOL	End of life
ETEM	Environmental transmission electron microscopy
FC	Fast charge
FCE	First-cycle efficiency
FEC	Fluoroethylene carbonate
FSP	Flame-spray pyrolysis
FTIR	Fourier-transform infrared
FY	Fiscal Year
g	Gram
GISAXS	Grazing incidence small-angle X-ray scattering
GM	General Motors
Go	Graphene oxide
H	Hydrogen
HF	Hydrofluoric acid
HOLE	Highly ordered laser-patterned electrode

HOMO	Highest occupied molecular orbit
IC	Internal combustion
ICL	Irreversible capacity loss
INL	Idaho National Laboratory
IP	Intellectual property
JES	*Journal of the Electrochemical Society*
kg	Kilogram
LATP	Lithium aluminum titanium phosphate
LBNL	Lawrence Berkeley National Laboratory
LCO	Lithium cobalt oxide ($LiCoO_2$)
LFP	Lithium-ion phosphate
LHCE	Localized high-concentration electrolyte
Li	Lithium
Li_2S	Lithium sulfide
LIB	Lithium-ion battery
$LiBO_2$	Lithium borate
LIC	Lithium-ion conducting
LiDFOB	Lithium diofluoro(oxalate) borate
LiEDC	Lithium ethylene dicarbonate
LiF	Lithium fluoride
LiFSI	Lithium bis(fluorosulfonyl)imide
LiPAA	Lithium polyacrylate
$LiPF_6$	Lithium hexafluorophosphate
LiTFSI	Lithium bis(trifluoromethanesulfonyl)imide
LLS	Layered-layered spinel
LLZO	Lithium lanthanum zirconate
LMB	Lithium-metal battery
LMNO	Lithium manganese nickel oxide

LMNOF	Li-Mn-Ni-O-F
LMR	Lithium-manganese rich
LNCO	Lithium nickel cobalt oxide
LNMO	$LiNi_{0.5}Mn_{1.5}O_2$
LNO	Lithium-nickel dioxide ($LiNiO_2$)
LT	Low temperature
LTMO	Lithium transition metal oxide
LTO	Lithium titanate
LUMO	Lowest unoccupied molecular orbit
M	Molarity
MA	Methyl acetate
mAh	Milliamp-hour
MD	Molecular dynamics
MERF	Materials Engineering Research Facility
min.	Minute
MLPC	Multi-layer pouch cell
Mn	Manganese
$MnCO_3$	Manganese carbonate
mV	Millivolt
N/P	Negative-positive ratio
Nb	Niobium
NCA	Nickel cobalt aluminum oxide
NCE	No-cost extension
NCM	Nickel cobalt manganese oxide
NFA	Nanostructured ferritic alloy
Ni	Nickel
NMA	Nickel manganese aluminum
NMC	Nickel manganese cobalt oxide

NMCA	Nickel manganese cobalt aluminum
NMP	N-methyl-2-pyrrolidone
NMR	Nuclear magnetic resonance
NN	Neural network
NREL	National Renewable Energy Laboratory
OEM	Original equipment manufacturer
OEMS	Online electrochemical mass spectroscopy
OIM	Organic insertion material
ORNL	Oak Ridge National Laboratory
PDF	Pair-distribution function
PEO	Polyethylene oxide
PI	Principal investigator
PNNL	Pacific Northwest National Laboratory
PP	Polypropylene
PS	Polysulfide
PSD	Pore-size distribution
PTO	Pyrene-4,5,9,10-tetraone
PV	Photovoltaics
PVDF	Polyvinylidene difluoride
Q	Quarter
R&D	Research and development
R2R	Roll-to-roll
RPC	Reactive-polymer composite
RST	Reactive-spray technology
S	Sulfur
SAW	Surface-acoustic wave
SEI	Silicon electrolyte interface
SEI	Solid electrolyte interphase

SEISTA	Silicon electrolyte interface stability
SEM	Scanning electron microscopy
SERS	Surface-enhanced Raman spectroscopy
SiO_x	Silicon Oxides
SLAC	Stanford Linear Accelerator Center
Sn	Tin
SNL	Sandia National Laboratories
SOA	State of the art
SOC	State of charge
SP	Solution process
SPAN	Sulfurized polyacrylonitrile
SSE	Solid-state electrolyte
STEM	Scanning transmission electron microscopy
TEM	Transmission electron microscopy
Ti	Titanium
TM	Transition metal
TNO	Titanium niobium oxide
TTE	1,1,2,2-tetrafluoroethyl-2,2,3,3-tetrafluoropropyl ether
UCSB	University of California at Santa Barbara
UMEI	University of Michigan Energy Institute
URI	University of Rhode Island
UT-Austin	University of Texas at Austin
V	Volt
VTO	Vehicle Technologies Office
Wh/kg	Watt-hour per kilogram
wt. %	Weight percent
XFC	Extreme fast charging
XPS	X-ray photoelectron spectroscopy

XRD	X-ray diffraction