3. Electrochemical Energy Storage

The Vehicle Technologies Office (VTO) supports early-stage research and development (R&D) to generate knowledge upon which industry can develop and deploy innovative energy technologies for the efficient and secure transportation of people and goods across America. VTO focuses on research that industry either does not have the technical capability to undertake or is too far from market realization to merit sufficient industry focus and critical mass. In addition, VTO leverages the unique capabilities and world-class expertise of the national laboratory system to develop new innovations for significant energy-efficiency improvement. VTO is also uniquely positioned to address early-stage challenges due to its strategic public-private research partnerships with industry (e.g., U.S. DRIVE and 21st Century Truck Partnerships) that leverage relevant technical and market expertise, prevent duplication, ensure public funding remains focused on the most critical R&D barriers that are the proper role of government, and accelerate progress – at no cost to the Government.

The Battery and Electrification Technologies subprogram supports early-stage R&D to explore new battery chemistry and cell technology with the potential to reduce the cost of electric vehicle batteries by more than half to less than $100/kWh and increase the range to 300 miles while decreasing the charge time to less than 15 minutes. The activity supports the development of innovative materials and cell technologies capable of realizing significant cost reductions in three major R&D areas. Advanced Battery Materials R&D will focus on early-stage R&D of new lithium (Li)-ion cathode, anode, and electrolyte materials, which account for 50%-70% of plug-in electric vehicle battery cost of current technologies. Advanced Battery Cell R&D effort will focus on early-stage R&D of new battery cell technology that contain new materials and electrodes that can reduce the overall battery cost, weight, and volume while improving energy, life, safety, and fast charging. Electrification R&D focuses on early-stage research to understand the potential impacts of electric vehicle (EV) charging on the Nation's electric grid.

Subprogram Feedback

DOE received feedback on the overall technical subprogram areas presented during the 2017 Annual Merit Review (AMR). Each subprogram technical session was introduced with a presentation that provided an overview of subprogram goals and recent progress, followed by a series of detailed topic area project presentations.

The reviewers for a given subprogram area responded to a series of specific questions regarding the breadth, depth, and appropriateness of that DOE VTO subprogram's activities. The subprogram overview questions are listed below, and it should be noted that no scoring metrics were applied. These questions were used for all VTO subprogram overviews.

Question 1: Was the program area, including overall strategy, adequately covered?

Question 2: Is there an appropriate balance between near- mid- and long-term research and development?

Question 3: Were important issues and challenges identified?

Question 4: Are plans identified for addressing issues and challenges?

Question 5: Was progress clearly benchmarked against the previous year?

Question 6: Are the projects in this technology area addressing the broad problems and barriers that the Vehicle Technologies Office (VTO) is trying to solve?

Question 7: Does the program area appear to be focused, well-managed, and effective in addressing VTO's needs?

Question 8: What are the key strengths and weaknesses of the projects in this program area? Do any of the projects stand out on either end of the spectrum?

Question 9: Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

Question 10: Has the program area engaged appropriate partners?

Question 11: Is the program area collaborating with them effectively?

Question 12: Are there any gaps in the portfolio for this technology area?

Question 13: Are there topics that are not being adequately addressed?

Question 14: Are there other areas that this program area should consider funding to meet overall programmatic goals?

Question 15: Can you recommend new ways to approach the barriers addressed by this program area?

Question 16: Are there any other suggestions to improve the effectiveness of this program area?

Responses to the subprogram overview questions are summarized in the following pages. Individual reviewer comments for each question are identified under the heading Reviewer 1, Reviewer 2, etc. Note that reviewer comments may be ordered differently; for example, for each specific subprogram overview presentation, the reviewer identified as Reviewer 1 in the first question may not be Reviewer 1 in the second question, etc.

Presentation Number: es000
Presentation Title: Overview of the DOE VTO Advanced Battery R&D Program
Principal Investigator: David Howell (U.S. Department of Energy)

Question 1: Was the program area, including overall strategy, adequately covered?

Reviewer 1:
The reviewer stated that the overall program was covered very well. The information provided allowed the audience to clearly see the advances made.

Reviewer 2:
The reviewer remarked that the project was definitely covered. The reviewer observed a clear picture of the multiple-level research approach. This reviewer noted some past success in helping science and engineering move to the point where U.S. firms can make profitable products, and highlighted a plan for the future that has risk, but is do-able.

Reviewer 3:
The reviewer commented that a clear and useful high-level understanding of the program area was given and overall strategy was covered.

Question 2: Is there an appropriate balance between near-, mid-, and long-term research and development?

Reviewer 1:
The reviewer considered the balance to be very good with the understanding that the funding budget may be changed.

Reviewer 2:
The reviewer observed good balance, saying that this was, perhaps, the U.S. Department of Energy's (DOE) best-balanced portfolio in this respect. This reviewer further explained that a healthy research portfolio feeds a smaller advanced program and then the United States Advanced Battery Consortium (USABC), as the single vector, is used to bring the products to beta stage. In addition, the usual Small Business Innovation Research (SBIR) program provides support that is common to all offices.

Reviewer 3:
The reviewer commented that the balance is not inappropriate, but that shifting balance to a greater degree towards nearer-term R&D may provide a greater impact to U.S. industry.

Question 3: Were important issues and challenges identified?

Reviewer 1:
The reviewer stated that the key issues and challenges were identified, and that both the technical and the associated cost issues were outlined.

Reviewer 2:
The reviewer said that the important issues and challenges were identified, both in the short-term (cost and energy density in the 350 Wh/kg region) and long-term (below $100/KWh). Additionally, this reviewer pointed out very high energy (lithium-sulfur [Li-S]), and of course, the new fast-charge focus.

Reviewer 3:
The reviewer said that cost and some of the major technical challenges were identified at a high level. Interaction with global industry is an important issue and an important challenge, but this reviewer remarked that it was not identified.

Question 4: Are plans identified for addressing issues and challenges?

Reviewer 1:
The reviewer commented that major areas for future work were identified related to addressing the cost challenge, and many of the major technical issues were identified.

Reviewer 2:
The reviewer stated that not only were plans covered in the talk, but also subcategorized by the various research areas in a battery. The plans seem quite appropriate as well, and described them as stretchy, but not silly.

Reviewer 3:
The reviewer noted that long- and short-term plans were highlighted that could address the issues and/or barriers, by using various technical solutions.

Question 5: Was progress clearly benchmarked against the previous year?

Reviewer 1:
The reviewer commented that the progress was clearly benchmarked.

Reviewer 2:
The reviewer remarked that progress was laid out in general over the last several years to include progress over the last year, not just 2016-17 versus 2015-16.

Reviewer 3:
The reviewer stated that progress in terms of battery cost reduction and energy density increase was clearly described.

Question 6: Are the projects in this technology area addressing the broad problems and barriers that the Vehicle Technologies Office (VTO) is trying to solve?

Reviewer 1:
The reviewer said yes.

Reviewer 2:
The reviewer asserted that the projects are addressing the broad problems and barriers that VTO is trying to solve.

Reviewer 3:
The reviewer thought so, and added that the projects are moving toward more sustainable, less polluting ways to move people and goods from place to place. Clearly, the projects are attacking the specific battery goals as well.

Question 7: Does the program area appear to be focused, well-managed, and effective in addressing VTO's needs?

Reviewer 1:
The reviewer stated that the program area was extremely well managed. Work is broken down into programs by Technology Readiness Level (TRL) (roughly, not a slavish TRL 1 task, a TRL 2 task, etc.). Work is also broken down within a program into project groups by the components of the battery with appropriate work in each of several programs. This reviewer commented that there are now numerous examples of projects flowing through this matrix organization as they have success and of course those not succeeding are dropped and do not move up the ladder. The programs talk to each other both at the researcher and DOE management level and

also to other DOE programs on battery or transportation outside the VTO. The reviewer said the focus, management, and effectiveness of this program area is splendid.

Reviewer 2:
The reviewer affirmed that the program area appeared to be focused, well-managed, and effective.

Reviewer 3:
The reviewer noted that the program area appears to be well-managed and somewhat focused. Long term effectiveness for VTO and for the United States may be improved by greater diversity of research partners and greater collaboration with global industry.

Question 8: What are the key strengths and weaknesses of the projects in this program area? Do any of the projects stand out on either end of the spectrum?

Reviewer 1:
The reviewer stated that the management is a strength, many of the highly talented, innovative and effective research groups are a strength, the advice form industry and other parts of government are also a strength. USABC stands out for industry support and being valued by American firms. The reviewer could not identify any weak projects from the talks.

Reviewer 2:
The reviewer stated that the projects related to potential near-to-mid-term implementation, which may have the ability to advance industry in the United States or globally (e.g., novel processing advances and high-voltage electrolytes), stand out most positively.

Reviewer 3:
The reviewer noted several key strengths of the projects, including involvement of the vast technical resources and collaboration of various national laboratories; the variety of technical approaches, appropriately funded to resolve technical issues, which increase the chances of the problem being overcome; and all aspects of the key battery system and the cell, which are being addressed. The reviewer indicated that a key weakness of the projects include some cost assumptions based on overcoming very difficult technical issues. Improvement in the nickel manganese cobalt oxide (NMC) cathode is a positive; nothing stands out for the weakness except maybe needing more work to resolve the silicon (Si) anode problems, and this is only because it appears to be near-term.

Question 9: Do these projects represent novel and/or innovative ways to approach these barriers as appropriate?

Reviewer 1:
The reviewer stated yes, and acknowledged that some are highly risky but could change the world. Others are more likely to make progress but of a less grand step. The reviewer concluded that the balance is good.

Reviewer 2:
The reviewer asserted that most projects represent novel and/or innovative ways to approach the barriers. Meanwhile, continued this reviewer, a lesser number of projects will still usefully advance the general knowledge base even if the projects less specifically and directly approach the barriers.

Reviewer 3:
The reviewer noted that the question was not very clear. The reviewer believed that the projects’ novel and innovative approaches to overcome the barriers are appropriate.

Question 10: Has the program area engaged appropriate partners?

Reviewer 1:
The reviewer said that the program area has very much engaged appropriate partners. Industry, government, and academia are all engaged.

Reviewer 2:
The reviewer stated that appropriate partners were engaged, although there are many researchers and battery companies outside the United States that could be added to the benefit of the work if that were permitted.

Reviewer 3:
The reviewer commented that there are a great number and variety of outstanding partners involved in projects. Increased balance towards industrial or research partners (versus national laboratories) may improve overall impact to industry. Greater partnership with global partners may also improve overall impact to industry.

Question 11: Is the program area collaborating with them effectively?

Reviewer 1:
The reviewer emphatically said yes.

Reviewer 2:
The reviewer remarked that the program was collaborating very effectively, both between projects and with industry, and with projects outside VTO.

Reviewer 3:
The reviewer commented that this program area has and continues to demonstrate effective collaboration with partners.

Question 12: Are there any gaps in the portfolio for this technology area?

Reviewer 1:
The reviewer observed no real gaps in the portfolio, presently. Fast-charge or Li plating were the only outstanding gaps and the program is filling that. This reviewer opined that this will be a powerful program if it gets the proper funding. Although the program may not need quite as much as was provided in the fiscal year (FY) 2017 budget, the reviewer noted that more is needed than the FY 2018 proposal.

Reviewer 2:
The reviewer stated that the technology area is generally well covered in the portfolio; however, there are some gaps. Areas such as battery cell hardware (cell can or cell pouch configuration and/or optimization, cell internal construction), as well as a coordinated effort in terms of battery abuse response improvement, may be among the gap areas.

Question 13: Are there topics that are not being adequately addressed?

Reviewer 1:
The reviewer noted that the only topic not adequately addressed is fast-charge and/or Li plating, and that is coming soon. Thus, the reviewer clarified that it is more a matter of being ramped-up than unaddressed. The need was identified last year, a workshop was held, and the team is setting up to fund projects.

Reviewer 2:
The reviewer commented that a key topic that does not seem to be adequately addressed is external outreach to and collaboration with global industry.

Question 14: Are there other areas that this program area should consider funding to meet overall programmatic goals?

Reviewer 1:

The reviewer said that there were no other areas. The reviewer considered this program to be well positioned.

Reviewer 2:

The reviewer stated that improving the vehicle components that use the electrical energy, and identifying some ways to incorporate capture of the mechanical energy being generated (while the vehicle is moving) in the form of electrical energy, are areas that could be considered.

Reviewer 3:

The reviewer suggested study, analysis, reporting, and reflection on battery research and the battery industry outside of the United States.

Question 15: Can you recommend new ways to approach the barriers addressed by this program area?

Reviewer 1:

The reviewer had no further recommendations. The reviewer considered the program to be well positioned. The reviewer approved of how the project currently spends money rather than on other work.

Reviewer 2:

The reviewer suggested putting greater focus and effort on battery manufacturing cost reduction and battery performance increase via battery manufacturing innovation.

Question 16: Are there any other suggestions to improve the effectiveness of this program area?

Reviewer 1:

The reviewer strongly said to keep the program funded.

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 3-1 – Project Feedback

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
es028	Materials Benchmarking Activities For CAMP Facility†	Wenquan Lu (ANL)	3-16	3.36	3.36	3.64	3.21	**3.38**
es030	Cell Analysis, Modeling, and Prototyping (CAMP) Facility Research Activities†	Andrew Jansen (ANL)	3-21	3.36	3.21	3.71	3.36	**3.33**
es049	Tailoring Integrated Layered- and Spinel Electrode Structures for High Capacity Lithium-Ion Cells	Michael Thackeray (ANL)	3-26	3.40	3.40	3.30	3.30	**3.38**
es052	Design of High-Performance, High-Energy Cathode Materials	Marca Doeff (LBNL)	3-31	3.00	3.00	3.50	3.25	**3.09**
es055	NMR and MRI Studies of SEI, Dendrites, and Electrode Structures	Clare Grey (U. of Cambridge)	3-37	3.70	3.50	3.70	3.30	**3.55**
es056	Development of High-Energy Cathode Materials	Jason Zhang (PNNL)	3-42	3.25	3.25	3.42	3.33	**3.28**
es059	Advanced *In Situ* Diagnostic Techniques for Battery Materials	Xiao-Qing Yang (BNL)	3-47	3.50	3.25	3.50	3.13	**3.33**
es085	Interfacial Processes in EES Systems Advanced Diagnostics	Robert Kostecki (LBNL)	3-51	3.50	3.63	3.13	3.25	**3.48**
es091	Predicting and Understanding Novel Electrode Materials From First-Principles	Kristin Persson (LBNL)	3-55	3.17	3.67	3.00	3.00	**3.38**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
es106	High-Capacity Multi-Lithium Oxide Cathodes and Oxygen Stability	Jagjit Nanda (ORNL)	3-58	3.17	3.00	3.17	2.92	**3.05**
es164	Thick Low-Cost, High-Power Lithium-Ion Electrodes via Aqueous Processing†	Jianlin Li (ORNL)	3-63	3.33	3.25	3.17	3.25	**3.26**
es166	Post-Test Analysis of Lithium-Ion Battery Materials†	Ira Bloom (ANL)	3-63	3.25	3.25	3.50	2.67	**3.21**
es167	Process Development and Scale-Up of Advanced Active Battery Materials—Gradient Cathode Materials†	Greg Krumdick (ANL)	3-71	3.33	3.33	3.42	3.50	**3.36**
es168	Process Development and Scale-Up of Critical Battery Materials—Continuous Flow Produced Materials†	Greg Krumdick (ANL)	3-75	3.50	3.57	3.36	3.50	**3.52**
es183	*In Situ* Solvothermal Synthesis of Novel High-Capacity Cathodes	Feng Wang (BNL)	3-79	3.75	3.50	3.50	3.42	**3.55**
es201	Electrochemical Performance Testing†	Ira Bloom (ANL)	3-84	3.50	3.38	3.63	3.38	**3.44**
es202	INL Electrochemical Performance Testing†	Matt Shirk (INL)	3-88	3.75	3.75	4.00	3.63	**3.77**
es203	Battery Safety Testing†	Leigh Anna Steele (SNL)	3-91	3.75	3.50	3.88	3.50	**3.61**
es204	Battery Thermal Characterization†	Matthew Keyser (NREL)	3-94	3.88	3.75	4.00	3.75	**3.81**
es207	Towards Solventless Processing of Thick Electron-Beam (EB) Cured Lithium-Ion Battery Cathodes†	David Wood (ORNL)	3-97	3.17	3.00	3.33	3.17	**3.10**
es220	Addressing Heterogeneity in Electrode Fabrication Processes	Dean Wheeler (Brigham Young U.)	3-101	3.70	3.40	3.50	3.30	**3.48**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
es225	Design and Synthesis of Advanced High-Energy Cathode Materials	Guoying Chen (LBNL)	3-105	3.50	3.50	3.67	3.17	**3.48**
es226	Microscopy Investigation on the Fading Mechanism of Electrode Materials	Chongmin Wang (PNNL)	3-108	3.63	3.63	3.50	3.50	**3.59**
es231	High-Energy Density Lithium Battery	Stanley Whittingham (Binghamton U.-SUNY)	3-111	3.33	3.17	2.92	3.08	**3.17**
es232	High-Energy Density Electrodes via Modifications to the Inactive Components and Processing Conditions	Vincent Battaglia (LBNL)	3-116	2.88	2.88	3.75	2.88	**2.98**
es235	Characterization Studies of High-Capacity Composite Electrode Structures	Michael Thackeray (ANL)	3-119	3.20	3.30	3.10	3.20	**3.24**
es240	High-Energy Anode Material Development for Lithium-Ion Batteries†	Cary Hayner (Sinode Systems)	3-124	3.00	2.63	3.00	2.75	**2.78**
es241	Advanced High-Performance Batteries for Electric Vehicle (EV) Applications†	Ionel Stefan (Amprius)	3-128	3.50	3.38	3.38	3.25	**3.39**
es247	High-Energy Lithium Batteries for Electric Vehicles†	Herman Lopez (Envia Systems)	3-132	3.38	3.38	3.75	3.13	**3.39**
es252	Enabling High-Energy/Voltage Lithium-Ion Cells: Electrolytes and Additives†	Dennis Dees (ANL)	3-136	3.50	3.40	3.30	3.40	**3.41**
es253	Enabling High-Energy/Voltage Lithium-Ion Cells: Theory and Modeling†	Dennis Dees (ANL)	3-140	3.50	3.63	3.50	3.38	**3.55**
es254	Enabling High-Energy/Voltage Lithium-Ion Cells: Materials Characterization†	Dennis Dees (ANL)	3-143	3.40	3.30	3.40	3.30	**3.34**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
es261	Next-Generation Anodes for Lithium-Ion Batteries: Overview†	Dennis Dees (ANL)	3-147	3.44	3.31	3.75	3.25	**3.39**
es262	Next-Generation Anodes for Lithium-Ion Batteries: Fundamental Studies of Si-C Model Systems†	Robert Kostecki (LBNL)	3-153	3.44	3.31	3.56	3.38	**3.38**
es263	Electrodeposition for Low-Cost, Water-Based Electrode Manufacturing†	Stuart Hellring (PPG)	3-158	3.30	3.40	3.30	3.30	**3.35**
es264	Li-Ion Battery Anodes from Electrospun Nanoparticle/ Conducting Polymer Nanofibers†	Peter Pintauro (Vanderbilt U.)	3-161	2.90	3.30	3.20	3.00	**3.15**
es265	UV Curable Binder Technology to Reduce Manufacturing Cost and Improve Performance of Lithium-Ion Battery Electrodes†	John Arnold (Miltec UV International)	3-164	3.40	3.20	3.00	3.20	**3.23**
es266	Co-Extrusion (CoEx) for Cost Reduction of Advanced High-Energy-and-Power Battery Electrode Manufacturing†	Ranjeet Rao (PARC)	3-168	3.25	3.25	3.50	3.13	**3.27**
es267	Commercially Scalable Process to Fabricate Porous Silicon†	Peter Aurora (Navitas Systems)	3-172	3.29	3.36	3.29	3.14	**3.30**
es268	Low-Cost Manufacturing of Advanced Silicon-Based Anode Materials†	Aaron Feaver (Group14 Technologies)	3-175	2.93	2.93	3.21	2.86	**2.96**
es269	An Integrated Flame Spray Process for Low-Cost Production of Battery Materials†	Yangchuan Xing (U. of Missouri)	3-179	2.70	2.50	2.60	2.60	**2.58**
es271	New Advanced Stable Electrolytes for High-Voltage Electrochemical Energy Storage†	Peng Du (Silatronix)	3-184	3.17	3.00	3.25	3.00	**3.07**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
es273	Composite Electrolyte to Stabilize Metallic Lithium Anodes	Nancy Dudney (ORNL)	3-188	3.75	3.50	3.75	3.63	**3.61**
es274	Nanoscale Interfacial Engineering for Stable Lithium Metal Anodes	Yi Cui (Stanford U.)	3-191	3.38	3.63	3.38	3.75	**3.55**
es275	Lithium Dendrite Prevention for Lithium-Ion Batteries	Wu Xu (PNNL)	3-194	3.50	3.25	3.50	3.38	**3.36**
es276	Mechanical Properties at the Protected Lithium Interface	Nancy Dudney (ORNL)	3-197	3.63	3.50	3.88	3.63	**3.59**
es277	Solid Electrolytes for Solid-State and Lithium-Sulfur Batteries	Jeff Sakamoto (U. of Michigan)	3-199	3.75	3.63	3.38	3.38	**3.59**
es278	Overcoming Interfacial Impedance in Solid State Batteries	Eric Wachsman (U. of Maryland)	3-201	3.50	3.33	3.33	3.50	**3.40**
es288	Construction of High-Energy Density Batteries†	Christopher Lang (Physical Sciences Inc.)	3-203	3.20	3.20	3.10	3.13	**3.18**
es289	Advanced Polyolefin Separators for Lithium-Ion Batteries Used in Vehicle Applications†	Weston Wood (Entek)	3-206	3.50	3.30	2.90	3.10	**3.28**
es290	Hybrid Electrolytes for PHEV Applications†	Surya Moganty (NOHMs Technologies)	3-209	3.13	3.13	3.13	2.88	**3.09**
es291	SAFT-USABC 12V Start-Stop Phase II†	Alla Ohliger (Saft)	3-213	3.25	3.38	2.88	3.00	**3.23**
es293	A Closed Loop Process for the End-of-Life Electric Vehicle Lithium-Ion Batteries†	Yan Wang (WPI)	3-217	3.30	3.20	3.30	3.10	**3.23**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
es296	Development and Validation of a Simulation Tool to Predict the Combined Structural, Electrical, Electrochemical, and Thermal Responses of Automotive Batteries	Chulheung Bae (Ford Motor Co.)	3-220	3.50	3.42	3.58	3.42	**3.46**
es298	Efficient Simulation and Abuse Modeling of Mechanical-Electrochemical-Thermal Phenomena in Lithium-Ion Batteries	Kandler Smith (NREL)	3-224	3.71	3.57	3.71	3.43	**3.61**
es299	Microstructure Characterization and Modeling for Improved Electrode Design	Kandler Smith (NREL)	3-229	3.50	3.50	3.71	3.57	**3.54**
es300	Enhancement and Deployment of VIBE, the Open Architecture Software (OAS) Environment	John Turner (ORNL)	3-233	3.42	3.33	3.50	3.42	**3.39**
es301	Experiments and Models for the Mechanical Behavior of Battery Materials	John Turner (ORNL)	3-237	3.58	3.58	3.42	3.42	**3.54**
es302	Microstructure Imaging and Electrolyte Transport Property Measurements for Mathematical Modeling	Venkat Srinivasan (ANL)	3-241	3.67	3.50	3.50	3.58	**3.55**
es303	Exploring How Electrode Structure Affects Electrode-Scale Properties Using 3D Mesoscale Simulations	Scott Roberts (SNL)	3-245	3.58	3.58	3.67	3.50	**3.58**
es304	Extreme Fast Charge and Battery Cost Implications	Shabbir Ahmed (ANL)	3-249	3.90	3.80	3.80	3.50	**3.79**
es305	Extreme Fast-Charging—Battery Technology Gap Assessment	Ira Bloom (ANL)	3-253	3.50	3.30	3.50	3.17	**3.36**
es306	Thermal Implications for Extreme Fast Charge	Matthew Keyser (NREL)	3-256	3.60	3.60	3.50	3.67	**3.60**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
es307	Discovery of High-Energy Lithium-Ion Battery Materials	Wei Tong (LBNL)	3-259	3.25	3.17	3.42	3.00	**3.20**
es309	Electrode Materials Design and Failure Prediction	Venkat Srinivasan (ANL)	3-264	3.67	3.50	3.00	3.17	**3.44**
es310	Advancing Solid-State Interfaces in Lithium-Ion Batteries	Nenad Markovic (ANL)	3-267	3.13	3.13	3.13	3.00	**3.11**
es311	Understanding and Mitigating Interfacial Reactivity between Electrode and Electrolyte	Larry Curtiss (ANL)	3-270	3.38	3.25	3.00	3.38	**3.27**
es312	Daikin Advanced Lithium-Ion Battery Technology – High-Voltage Electrolyte	Joe Sunstrom (Daikin America)	3-274	3.50	3.13	2.63	3.13	**3.16**
es313	Performance Effects of Electrode Processing for High-Energy Lithium-Ion Batteries†	David Wood (ORNL)	3-277	3.00	3.42	3.25	3.08	**3.25**
es315	Developing Flame Spray Production Level Process for Active Materials†	Greg Krumdick (ANL)	3-282	3.00	3.00	3.17	3.08	**3.03**
es331	Development of a High-Energy Density EV Cell†	Mohamed Alamgir (LG Chem Power)	3-286	3.17	3.17	3.00	3.17	**3.15**
es332	High Electrode Loading EV Cell†	William Woodford (24M Technologies)	3-289	3.50	3.13	2.75	2.75	**3.13**
es333	Silicon Electrolyte Interface Stabilization Focus Group†	Anthony Burrell (NREL)	3-293	3.71	3.21	3.64	3.50	**3.43**
es334	Insights from Mesoscale Characterization Guides Rational LIB Design	William Chueh (Stanford U.)	3-298	3.75	3.63	3.00	3.63	**3.58**
es335†	Next-Generation Anodes for Lithium-ion Batteries: Materials Advancements	Zhengcheng Zhang (ANL)	3-301	3.25	3.31	3.69	3.25	**3.34**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
es336	Extreme Fast Charging (XFC) Gap Assessment†	Christopher Michelbacher (INL)	3-306	3.80	3.50	3.90	3.75	**3.66**
Overall Average				**3.40**	**3.33**	**3.40**	**3.26**	**3.35**

† Denotes a poster presentation.

Presentation Number: es028
Presentation Title: Materials Benchmarking Activities For CAMP Facility
Principal Investigator: Wenquan Lu (Argonne National Laboratory)

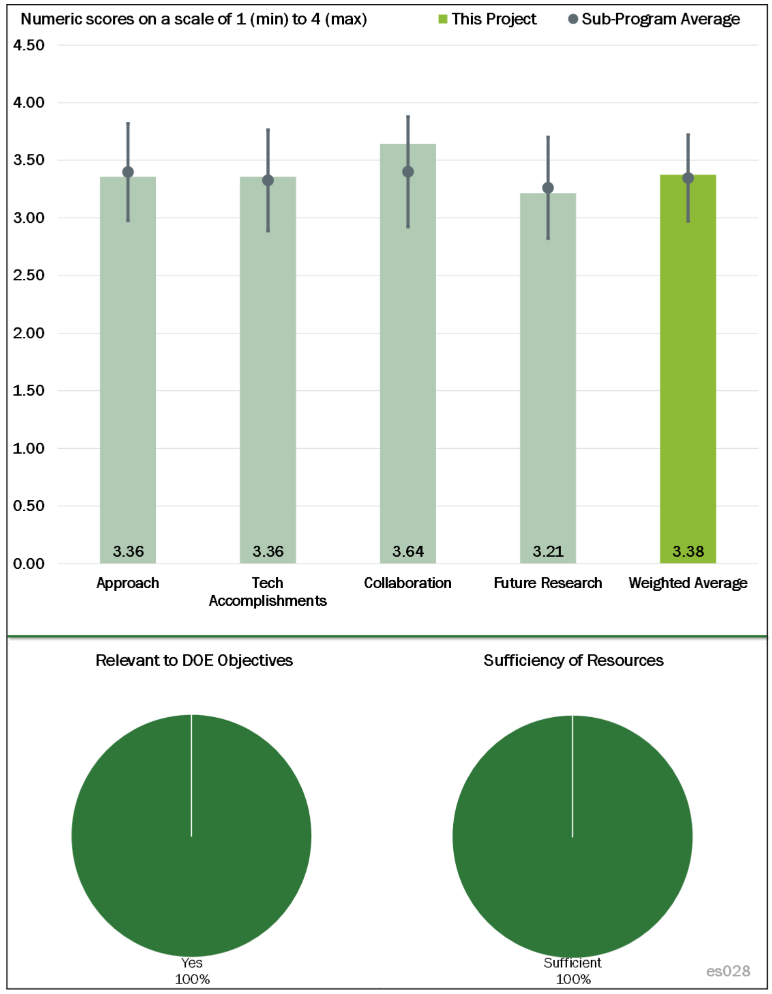

Figure 3-1 – Presentation Number: es028 Presentation Title: Materials Benchmarking Activities For CAMP Facility Principal Investigator: Wenquan Lu (Argonne National Laboratory)

Presenter

Wenquan Lu, Argonne National Laboratory

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer stated that the goal is to provide developers with a way to benchmark their materials. A powerful suite of tests has been developed.

Reviewer 2:

The approach and materials used to benchmark the material produced at the Argonne National Laboratory (ANL) Cell Analysis, Modeling, and Processing (CAMP) Facility are appropriate and industrially relevant. The identification, characterization, and validation (a.k.a. "benchmarking") of these materials is extremely useful especially when combined with the other activities of CAMP to supply the benchmarked material and serve as a standardization body. This is extremely necessary in order to provide relatable testing between research groups.

Reviewer 3:

The reviewer commented that the project approach is balanced with good fundamental planning and scientific approach combined with practical approach focusing on things that are relevant in the final commercial application.

Reviewer 4:

The reviewer noted that the major issue in the approach is that work seems to be limited to coin cells. Coin cell tests are an acceptable way to identify gross details of cell and material behaviors; they are more limited in assessing subtle differences. Some of the claimed improvements associated with coating NMC532 (nickel manganese cobalt oxide) materials are relatively small. They should be confirmed in larger cells constructed using techniques similar to the techniques used to manufacture vehicular cells.

The reviewer stated that a separate issue is related to the basic nature of this project as this is a benchmarking effort whose goal is to collect data on materials that are already available from commercial sources. The modifications studied in this project, such as coating the NMC and using carbon nanotubes as part of the conductive mix, are not really new—they have been extensively investigated by other laboratories and industry.

According to the reviewer, the major benefit of this effort is that it provides independent data on the performance of "commercial" materials; these data can then be compared with similar data from new materials.

Reviewer 5:

This reviewer would like to have seen different and larger cell formats evaluated after the initial coin cells indicate very positive results.

Reviewer 6:

The reviewer stated that the approach to validate electrochemical performance of high-energy materials using coin cell under test protocol derived from the plug-in hybrid electric vehicle (PHEV) having a 40-mile range (PHEV40) requirement is well designed and feasible. The principal investigator (PI) should provide more information regarding the PHEV40 requirements conversion to C-rate and pulse current for coin cells. The work can be further improved by addressing one of the technical barriers related to cost.

Reviewer 7:

The reviewer found that the project provides validation and support for other DOE-sponsored battery developers, thus providing useful information and integration, but does not focus on new material discovery.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This reviewer described the CAMP project as very successful, especially given the limited availability of some of the materials needed to meet the stated DOE goals. The progress in establishing useful evaluation processes for the various components was excellent and should lead to testing and evaluation improvements in the industry.

Reviewer 2:

The reviewer observed that the project studied carbon black (CB) distribution, which is normally ignored, but which can be important. The project provided numerous standard performances for materials of interest.

Reviewer 3:

The reviewer commented that the project has met most of the proposed technical goals.

Reviewer 4:

The reviewer stated that the project has provided useful information on NMC, alumina coated NMC, single-wall carbon nanotubes (SWCNT), and separator materials.

Reviewer 5:

As noted in the discussion of the Approach, this project benchmarks existing materials. The reviewer stated that there is relatively little in this project that advances technology per se. Benchmarking is important because it lets one understand the limits of the state-of-the-art, but benchmarking per se does relatively little to advance the state-of-the-art.

The reviewer remarked that many of the results mentioned in the poster presentation are not new. For example, coating of cathode materials with aluminum oxide (Al_2O_3) has been investigated for years, and the degradation of some commercial separators at higher voltages has been known—at least by the separator companies—for several years.

Reviewer 6:

The reviewer pointed out that the program focused on improved NMC532 materials over the previous year and included relevant results showing improved electrochemical results via the incorporation of Al_2O_3 surface coatings. The choice of materials and coatings is useful, and the results demonstrate the ability to make progress toward DOE goals (improved capacity, rate, and capacity retention with high-energy cathodes). However, the reviewer noted that it is not clear how much energy density improvement will be feasible through the exchange of CB with SWCNT. The reviewer wanted to see a more in-depth analysis and modeling of the benefits.

Reviewer 7:

The reviewer noted that there has been a lot of progress on modifying high energy density cathode materials, pre-lithiated anodes, and carbon additives. The work can be improved by validating more commercialized samples from various industry partners listed in the presentation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer observed that the collaboration between the various groups was excellent. The national laboratory involvement and the broad supplier base were excellent. This reviewer would like to have seen a larger number of high-volume suppliers involved in the project.

Reviewer 2:

The reviewer found the list of collaborators both from academic and national laboratories and industry to be outstanding.

Reviewer 3:

The reviewer praised the extensive collaboration in this project, both internally between groups as well as externally with other research institutions and industrial companies.

Reviewer 4:

The reviewer said that there was a very wide range of collaborators and co-investigators, as with everything in CAMP

Reviewer 5:

The reviewer said that there was collaboration with numerous battery development groups.

Reviewer 6:

The reviewer commented that the poster presentation clearly lists collaborators in industry and other laboratories, but there is no discussion as to how this collaboration functions or the benefits gained from collaboration.

Reviewer 7:

The reviewer described collaboration activities within the national laboratory and with universities as fairly coordinated. The PI should encourage the industry partners to get more involved in the research activity, especially to help benchmarking high energy materials and providing more commercialized samples for testing.

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.

Reviewer 1:
The reviewer remarked that focusing on a Si-based anode seems logical.

Reviewer 2:
The reviewer stated that the project will expand validation work to other high-energy anode and cathode materials of interest, as well as collaborations.

Reviewer 3:
The reviewer commented that the presentation lists several materials that will be benchmarked in the future. All of these materials are of interest to the battery community.

No specific decision points or barriers were explicitly defined. Given that benchmarking is more "test and evaluation" than it is "research," the lack of decision points and discussion of barriers is not a disabling flaw.

Reviewer 4:
The reviewer commented that the future plan was very logical and fairly complete. This reviewer would like to have seen the inclusion of larger format cells with different cell designs included as part of the plan for future work.

Reviewer 5:
The reviewer stated that appropriate plans have been described, but did not see any efforts to develop new diagnostics that could be valuable for developers, such as post-mortem analyses.

Reviewer 6:
The reviewer observed that the broad future plan appears appropriate, but more specifics are required to accurately determine the quality of the proposed future research. The reviewer suggested that there should be emphasis on higher energy NMC materials and Si-based materials. This project should be aligned with serving to assist in solving the most pressing issues required to advance lithium-ion battery (LIB) technology significantly.

Reviewer 7:
The reviewer asserted that the PI should focus more on validating or studying high energy electrodes and sharply focus on the most critical barriers. Meanwhile, the PI should deemphasize divergent effort on binders and conductive additives.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that there is a high cost associated with reaching the objective of displacing petroleum as the default fuel for transportation vehicles. The only way that this objective can be reached by industry is by support of DOE through such projects as the CAMP Facility. This project allows for innovative processes that can lead to materials developments to be expertly evaluated at a significant cost savings to the supplier.

Reviewer 2:
The reviewer said that the project objectives are very well aligned.

Reviewer 3:
The reviewer acknowledged that the benchmarking activity is important to provide an objective opinion on promising battery materials to battery materials developers. This will accelerate the materials development and EV adoption.

Reviewer 4:
The reviewer stated that implementation of new materials will help improve battery performance to achieve desired commercial adoption of electric vehicles (EVs).

Reviewer 5:
The reviewer said yes. This project aids in the development of new materials for EV applications both directly (benchmarking) and indirectly (collaboration).

Reviewer 6:
The reviewer said that these battery improvements will advance vehicle electrification and thus displace petroleum consumption.

Reviewer 7:
The reviewer noted that in order to meet the overall DOE objectives, new batteries containing new materials will be required. Part of the process of developing new materials is the understanding of the state-of-the-art. This project helps provide that understanding.

The reviewer also commented that this project was reported at the AMR in more than one poster, but this reviewer was assigned to review only this presentation. Reviewing only part of a project may have resulted in overlooking some data included in the other presentations.

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

Reviewer 1:
The reviewer remarked that the funding provided meets the needs of the suppliers identified.

Reviewer 2:
The reviewer noted that resources are okay.

Reviewer 3:
The reviewer said that the resources are sufficient for the project to achieve the stated milestones in a timely fashion.

Reviewer 4:
The reviewer noted that resources are sufficient to achieve milestones.

Reviewer 5:
The reviewer found resources and funding to be in line with the work scope.

Reviewer 6:
The reviewer commented that there is no information in the presentation or in discussions with the presenter to indicate that the resources are excessive or inadequate. Funding is such that this is only a part of the larger CAMP effort.

Reviewer 7:
The reviewer found resources and funding to be sufficient for this project but would like to have seen larger cells being tested for benchmarking purposes as well as potentially serving as an independent third-party validator for industrial materials.

Presentation Number: es030
Presentation Title: Cell Analysis, Modeling, and Prototyping (CAMP) Facility Research Activities
Principal Investigator: Andrew Jansen (Argonne National Laboratory)

Presenter
Andrew Jansen, Argonne National Laboratory

Reviewer Sample Size
A total of seven reviewers evaluated this project.

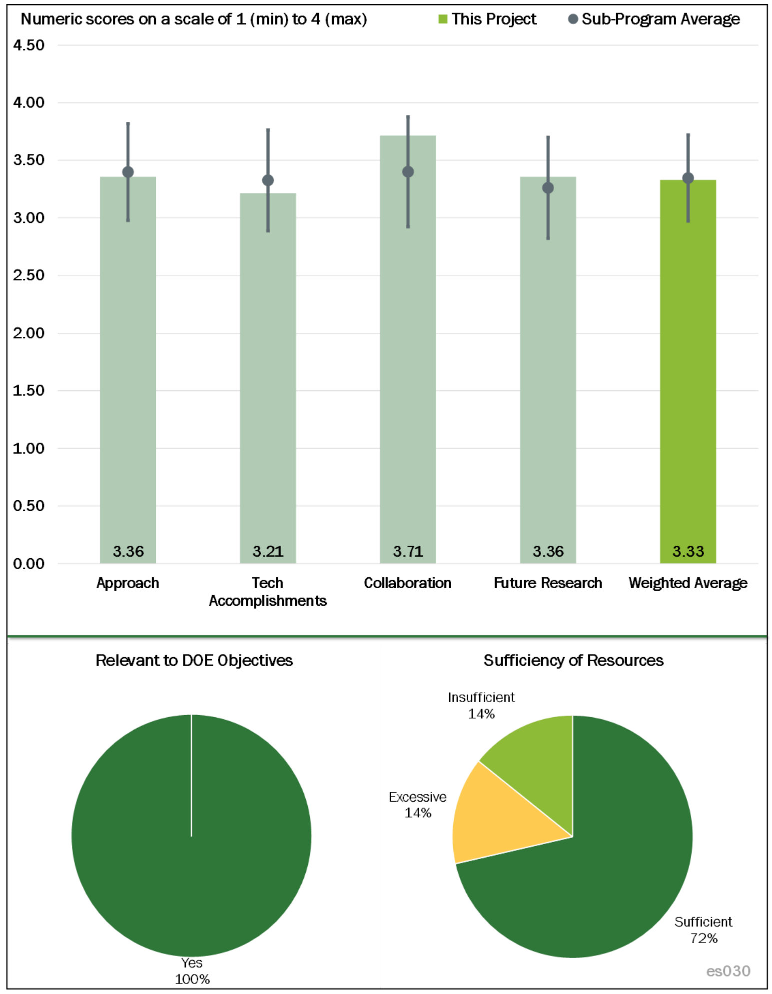

Figure 3-2 – Presentation Number: es030 Presentation Title: Cell Analysis, Modeling, and Prototyping (CAMP) Facility Research Activities Principal Investigator: Andrew Jansen (Argonne National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer said that the goal is to be a resource for small-scale powder producers so that they can get high quality cells made. Extensive diagnostics are available. An outstanding laboratory has been assembled for these purposes.

Reviewer 2:
The reviewer commented that this project coordinates very well with the other aspects of the CAMP project. The approach addresses some of the areas that this reviewer mentioned as concerns in the ES028 project.

Reviewer 3:
The reviewer remarked that CAMP is providing a useful platform to provide relevant materials across the industry to various academic, industrial, and government institutions. The projects provide the required standardization of many electrode materials.

Reviewer 4:
The reviewer found that the technical barriers are well addressed. The projects, which are designed to validate the materials from coin cell level to pouch cell level, will effectively evaluate the feasibility of the new materials commercialization.

Reviewer 5:
The reviewer observed that the approach is logical and designed to systematically address issues confronting the development of a safe, affordable battery that meets DOE and USABC goals. Materials are tested in realistic pouch cell or 18650 formats.

Reviewer 6:

The reviewer stated that the PI and team are progressing and contributing to the general knowledge base concerning LIBs. However, it appears that work is most all "experimental with no up-front computational work (either Materials Genome Initiative [MGI] or integrated computational materials engineering [ICME])" being first accomplished. As a result, it seems that the experimental approach wanders year to year without a formal go/no-go established to determine when the team should instead prioritize other efforts and move away from Si-Li-ion materials, etc. It is apparent that process and equipment are under a state of constant refinement. However, this creates a significant issue. The reviewer asked when a result is determined, is it due to process refinement or because of materials design. A baseline needs to be established from which all work can be referenced.

Reviewer 7:

The reviewer pointed out that there was too much information in the slides, and that the PI should focus.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer remarked that CAMP has been successfully supporting other DOE projects and collaborating with other DOE laboratories. The validation activity show good progress toward DOE goals.

Reviewer 2:

The reviewer commented that significant accomplishments were made, including evaluations of lithium bis(fluorosulfonyl)imide (LiFSI) and lithium 4,5-dicyano-2-trifluormethyl-imidazolide -based electrolytes and improvements to Si composite anodes.

Reviewer 3:

This reviewer felt that there was significant progress toward this project's and DOE's goals, particularly in the area of understanding and evaluation of degradation in Si anodes. The addition of the evaluation work on some high-energy, high-voltage cathodes and electrolytes to the overall CAMP library helps the battery community narrow the selections to obtain desired performance.

Reviewer 4:

The reviewer stated that an enormous amount of work has been accomplished. It would be even better if the data were analyzed with models that aimed to make predictions for new or modified systems.

Reviewer 5:

The reviewer observed that the team, which to date has not met DOE objectives, does formulate and execute plans to overcome encountered barriers. What remains to be established is whether the principal issue is quality, process, or simply the material set that is being used in support of the project. It seems that the project has "stalled," and the team reports minimal progress. This, of course, is due to a myriad of reasons, such as changing composition, loss of the supply chain for Si materials, an apparent issue with materials variability due to process, etc. If the program is continued, a precise and comprehensive metric set needs be established against which the team must work.

Reviewer 6:

The reviewer commented that the project appears to be making sufficient progress on investigating new nickel cobalt manganese oxide (NCM) cathode materials and various acceptable voltage cutoffs. The Si benchmarking effort seems to be significant, but the progress toward the DOE goals appears limited. The reviewer would like to have seen if CAMP were able to assist technical accomplishments of industrial partners to a noticeable extent.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer remarked that the group is making a real impact by providing data and guidance to a very large number of clients and commented that this was very, very impressive.

Reviewer 2:
The reviewer asserted that CAMP provides a critical role in developing and supplying standardized materials for various government, research, and industrial organizations. CAMP's collaboration and outreach is significant and extremely necessary.

Reviewer 3:
The reviewer observed that the collaborations are outstanding, and include the national laboratories, numerous industry partners, and universities.

Reviewer 4:
The reviewer commented that the team reports considerable interaction among PIs at Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), and the National Renewable Energy Laboratory (NREL) as well as with subject-matter experts (SMEs) from other sectors.

Reviewer 5:
The reviewer stated that this project lists a wide assortment of collaborators from industry leaders, in addition to national laboratories and various universities.

Reviewer 6:
The reviewer said that CAMP has been successfully supporting other DOE projects and collaborating with other DOE laboratories.

Reviewer 7:
The reviewer warned that the numbers of collaborations was too much, and the PI must select the best institution to meet the DOE goal.

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.

Reviewer 1:
The reviewer enthused about not being able to imagine a better list of challenges for future work and hoping to see much progress next year.

Reviewer 2:
The reviewer noted that the proposed future efforts are very outstanding. Efforts will be initiated to understand the limitations of Li-metal anodes. The team will attempt to develop techniques for in-operando detection of Li plating during fast charging.

Reviewer 3:
The reviewer stated that the proposed future research is logical and far-reaching (Si, Li plating; cathodes; conductive binder; electrode processing; etc.). The project serves an important role in ensuring validity of many other ongoing projects within DOE. The reviewer wanted to see more results regarding analysis and prototyping of advanced industrial R&D materials.

Reviewer 4:
The reviewer commented that the team suggests seven tasks for the upcoming fiscal year. Overall, it seems that individually the tasks deserve priority. However, within the scope of this project, that seems overly broad. Instead, the reviewer suggested that the team should select narrowly defined tasks so as to enable focus on the ultimate DOE objective and not be distracted by lower priority issues.

Reviewer 5:
The reviewer opined that during the validation process of the newly developed materials, new technical problems of new chemistries related to the cell designs surely will show up. It is critical for the CAMP PIs to closely work with the developers to close the feedback loop. This should be emphasized in the future plan.

Reviewer 6:
The future work plans address the current concerns and issues that were identified during the project. One comment is that the future plans for this project appear to be beyond the identified current resources for this project.

Reviewer 7:

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer commented that this project moves the materials development needed to meet DOE objectives forward at a faster rate than would be possible without the DOE support to establish and support both industry and national laboratory involvement in this collaborative project.

Reviewer 2:
The reviewer stated that the CAMP activity is important to provide an objective opinion on the promising battery materials to the battery materials developers. This will accelerate the materials development and EV adoption.

Reviewer 3:
The reviewer noted that CAMP serves an important role in developing electrodes to accelerate progress toward vehicle electrification and petroleum displacement.

Reviewer 4:
The reviewer affirmed that this effort is highly relevant to the overall success of the DOE and USABC program.

Reviewer 5:
The reviewer found the project to be very relevant.

Reviewer 6:
The reviewer said battery for EVs and PHEV

Reviewer 7:
Although developing a lightweight, high-capacity “battery” reduces transportation energy need due to weight reductions obtained when introduced to vehicles, it remains a battery focused on energy storage, regardless of generating source.

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

Reviewer 1:
The reviewer found the resources to be OK.

Reviewer 2:
The reviewer said that the resources are sufficient for the project to achieve the stated milestones in a timely fashion.

Reviewer 3:
The reviewer said that the funding is sufficient for the current level of effort, but thinks, however, that the funding would not be sufficient for the extensive future plans outlined.

Reviewer 4:
The team has made significant advances in establishing materials and processes set in the fabrication of LIBs. However, it seems that, unless the discovery of new materials yields properties to meet the stated DOE objectives, a compromise needs be made resulting in new objectives for this program that are not quite so ambitious.

Reviewer 5:
The reviewer stated that the project should keep the same resources and focus.

Reviewer 6:
The funding may be slightly on the high side considering that outside parties most likely contribute additional funds for their work done at CAMP. It is unclear if the budget includes funding for related DOE projects (such as ES028) or if they have their own budget as well. Much work in the presentation focused on coin cells (only some anodes tested in pouch cells) although the facility boasted equipment upgrades (2 ampere hour [Ah] pouch cells; 18650).

Presentation Number: es049
Presentation Title: Tailoring Integrated Layered- and Spinel Electrode Structures for High Capacity Lithium-Ion Cells
Principal Investigator: Michael Thackeray (Argonne National Laboratory)

Presenter

Michael Thackeray, Argonne National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

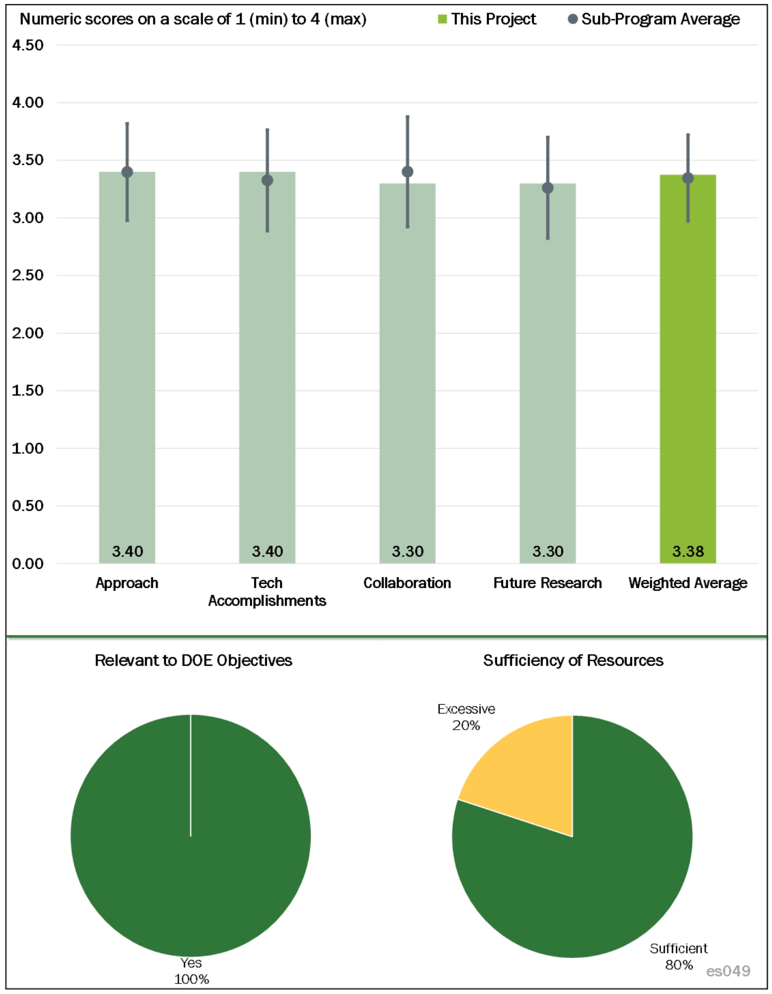

Figure 3-3 - Presentation Number: es049 Presentation Title: Tailoring Integrated Layered- and Spinel Electrode Structures for High Capacity Lithium-Ion Cells Principal Investigator: Michael Thackeray (Argonne National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer remarked that, as always, the PI does great hypothesis driven research. The approach is systematic and builds on the learnings as it progresses. There is a nice consideration of the balance of effects as deficiencies in the Li-rich material are addressed.

Changing the spinel component to include cobalt (Co) seems promising and shows the progression of thought in the project.

Reviewer 2:

The reviewer commented that the objective here is to develop structurally integrated cathode structures, specifically layered-layered-spinel (LLS), to overcome the inherent issues associated with the layered-layered (LL) composite cathodes, including voltage fade, poor cyclability and poor rate capability of the Li-rich, manganese (Mn)-rich LL composite oxides. These materials are expected to have comparable performance (i.e., high capacity at high rate) like the nickel (Ni)-rich layered oxides (622 or 811).

There is an advantage with these Mn-rich LLS composites in abuse resistance, but it is not clear if these materials provide comparable capacity (approximately 240 mAh/g) and energy (low discharge voltage) with the Ni-rich layered cathodes with similar surface coatings, especially with comparable electrode loadings (not specified here). Likewise, the development of Co-and Ni-based spinel compounds, as components of these LLS structures, looks encouraging because of their higher voltages, but may also pose more safety issues compared to Mn-rich spinels.

Nevertheless, these studies provide an excellent platform to understand the Mn-rich LLS composite cathodes and also to tune the transition metals (with Co and Ni spinels) to optimize specific energy, cost, and safety.

Low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles, which these LLS composite cathodes will duly address.

The present project is well designed with new cathode structures, feasible as shown by the experimental data, and adequately integrated with the other DOE efforts on the high-capacity LL cathodes.

Reviewer 3:

The reviewer stated that the approach of lattice parameter matching of spinel coatings is reasonable because improving the stability of the previous high-capacity, LL material should be the highest priority.

Reviewer 4:

The reviewer noted that the energy density is significantly increased with over 200 mAh/g at more than 1° Celsius (C) obtained. The stability remains a challenge to overcome.

Reviewer 5:

The reviewer pointed out that the project focuses on finding optimum compositions and atomic arrangements to stabilize bulk and combat internal phase transitions through embedding spinel-type defects. The approach is good for answering the fundamental questions on the limitations of this family of materials, but does not address the practical side. The reviewer asked can these complex compositions be reproduced on the large scale, and what would be the quality control measures.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer pointed out that with spinel coatings, the material appears to have gained some stability over cycles. In addition, the rate capability also has been improved. However, the materials in this series need to be charged to much higher voltages compared to lithium-cobalt oxide (LCO). The stability of material—including decomposition and reaction with electrolytes over hundreds cycles—is still in question.

The reviewer expressed doubt about whether the oxidation states of each transition metal as a function of voltage during charge-discharge cycles have been thoroughly examined. It appeared to this reviewer that it was difficult to explain the large capacity by Ni_{2+} and Ni_{4+} alone. In the case of NMC, many have claimed charge storage on oxygen with no changes in Mn, which was difficult for this reviewer to believe.

Examining the very first charge, i.e., the initial activation of very high capacity using X-ray absorption near edge structure (XANES) and differential electrochemical mass spectroscopy (DEMS) seems to be very important to understand the LL or LLS materials better. The reviewer asked what is basically so much oxidized beyond Ni, and said O_2 evolution creating O_2 deficiency with Mn (III). It is not clear just by looking at the formula.

Reviewer 2:

The reviewer stated that excellent progress has been made in designing the LL cathodes with embedded spinel component. With such embedded spinel component (of 6%), good cyclic stability was demonstrated without reduced voltage fade. It appears that maximum specific capacities of these LLS cathodes with good cyclic stability and low voltage fade are around 220 mA/g, slightly lower than the Ni-rich oxide cathode. The designed composite structures with domains of layered and spinel phases were confirmed through X-ray diffraction (XRD) and high-resolution transmission electron microscopy (HRTEM). New surface coatings have been developed that allow the LLS cathodes to operate at high charge voltages. In addition, new high-potential (approximately 3.5 volt [V]), lithiated Co- and Ni-based spinels have been evaluated as potential components for LLS electrode systems. Also, several good publications have emerged from this project.

The reviewer offered a couple of questions, however. The reviewer asked could the 6% of spinel component be expected to stabilize 94% of the LL structure for extended periods of operation (beyond hundreds of cycles and months of operation), and if there is any direct evidence for the elimination of the transition metal (TM) migration. There is evidence for the local domains of spinel and layered phases, but the reviewer asked would it be possible to verify if the spinel content (in the bulk) is close to the targeted 6%, and are the electrode loadings here are close to the practical values of 30 mg/cm^2.

Overall, the technical accomplishments are significant and demonstrate the progress toward DOE goals.

Reviewer 3:
The reviewer commented that the first objective has been completed. The second one is on track to have improved stability but not yet achieved.

Reviewer 4:
The reviewer noted that the project goals are being met, but asked if perhaps they were not challenging enough. The reviewer thought the learnings in this project can be applied to ultimately exceed the original goals.

The reviewer appreciated the acknowledgment of complexity in processing as it is hard to control both composition and structure, and more work needs to be done here.

Reviewer 5:
Embedding lithiated Co-rich spinels make sense, but the reviewer questioned whether it will also add cost and safety concerns.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer acknowledged that the effort seems to be focused at ANL, which the reviewer thought was actually appropriate as this group is in the best position to solve the challenges in Li-rich NMC.

Reviewer 2:
The reviewer stated that this project team works with colleagues from ANL, Pacific Northwest National Laboratory (PNNL), a university, and also industry for the materials synthesis, characterization, and scale-up tests.

Reviewer 3:
The reviewer remarked that there are good collaborations with several researchers from ANL and also with external researchers in understanding these materials at the fundamental level. It would be more appropriate and timely to collaborate closely with industry, especially the licensees (BASF, Toda, LG, and Envia), to establish the merit and relevance of these materials compared to nickel-cobalt-aluminum oxide (NCA)-based cathodes or Ni-rich cathodes. Such interactions with industry to evaluate ANL's baseline LLS electrodes and surface-treated materials have been initiated.

Reviewer 4:
The reviewer would like to have seen K-edge XANES data through 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.

Reviewer 1:

The reviewer said that the proposed future research is to continue the development of these LLS cathodes with new surface coatings to optimize specific capacity, operating voltage, rate, and cyclic stability. Preliminary results on the new, high-potential (3.5V), lithiated Co- and Ni-based spinels are encouraging and have opened up new opportunities for material development, which will be pursued here.

It is, however, important to demonstrate the benefits of these LLS cathode materials in an industrial environment in comparison with the surface-treated NCA-based cathode to properly the technical barriers in the VTO program. Future efforts will have collaborative interactions with industry to evaluate the baseline LLS electrodes and surface-treated materials.

Reviewer 2:

The reviewer commented that promising results on a Co-based spinel component will be a focus in the future, acknowledgment of characterization and process needs is encouraging, and there is a realistic approach recognizing trade-offs as the material is improved.

Reviewer 3:

The reviewer was interested in seeing any statistical data as they relate to the compositional control.

Reviewer 4:

The reviewer hoped to see more practical data using standard form factor cells in a full cell mode even though in small number of cells are constructed.

Reviewer 5:

First of all, the reviewer noted, Co is toxic and known to be the expensive element to avoid for low-cost electrode making. Thus, the reviewer had reservation in the further exploration of this material in LLS study.

Secondly, the listed future work seems on the optimization of the LLS to achieve the goals. This is necessary. However, to improve the stability, there should be more effort in the surface and structural design rather than only the chemistry of elemental differences in the composition.

Thirdly, the scale-up work would be also industrially interesting to be carried out.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer observed that low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles. High specific energy cathode materials (at high discharge rates) with reduced cost and improved safety are required to address these shortcomings. The LLS composite cathodes with suitable surface coatings are promising to provide stable structures with high capacities at high rates and are being addressed in this project.

This project is thus highly relevant to the DOE goals.

Reviewer 2:

The reviewer noted that energy storage is important for renewable energy supplies. The cheap and high-density cathode material is essential for the development of compact LIBs for energy storage and power supply. The project aims to have the material for the next generation of high-voltage cathode materials for EV applications. This would support the overall DOE objectives of petroleum displacement.

Reviewer 3:

The reviewer commented that any technology development focused on improving energy density of LIBs addresses the overall DOE objective.

Reviewer 4:

The reviewer said yes.

Reviewer 5:

The reviewer agreed that LLS composite structures still hold promise, but Ni-rich cathodes are not in vogue; they have been commercialized.

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

Reviewer 1:

The reviewer said the resources for the project are well organized.

Reviewer 2:

The reviewer remarked that the first objective of high energy density has been achieved with excessive results over the target value. The second objective of a stable electrode is in progress. The reviewer believes the research can have impressive results in the next part of the project.

Reviewer 3:

The reviewer asserted that a steady, consistent effort on Li-rich is the right way to go. The entire battery community focused on this, with fragmented efforts. As previously stated, this group is uniquely positioned to solve this hard problem.

Reviewer 4:

The reviewer commented that the resources may be slightly in excess for the scope of the project, and was not sure why the funds are divided over two different tasks of composite electrodes and spinel components, which are related.

Presentation Number: es052
Presentation Title: Design of High-Performance, High-Energy Cathode Materials
Principal Investigator: Marca Doeff (Lawrence Berkeley National Laboratory)

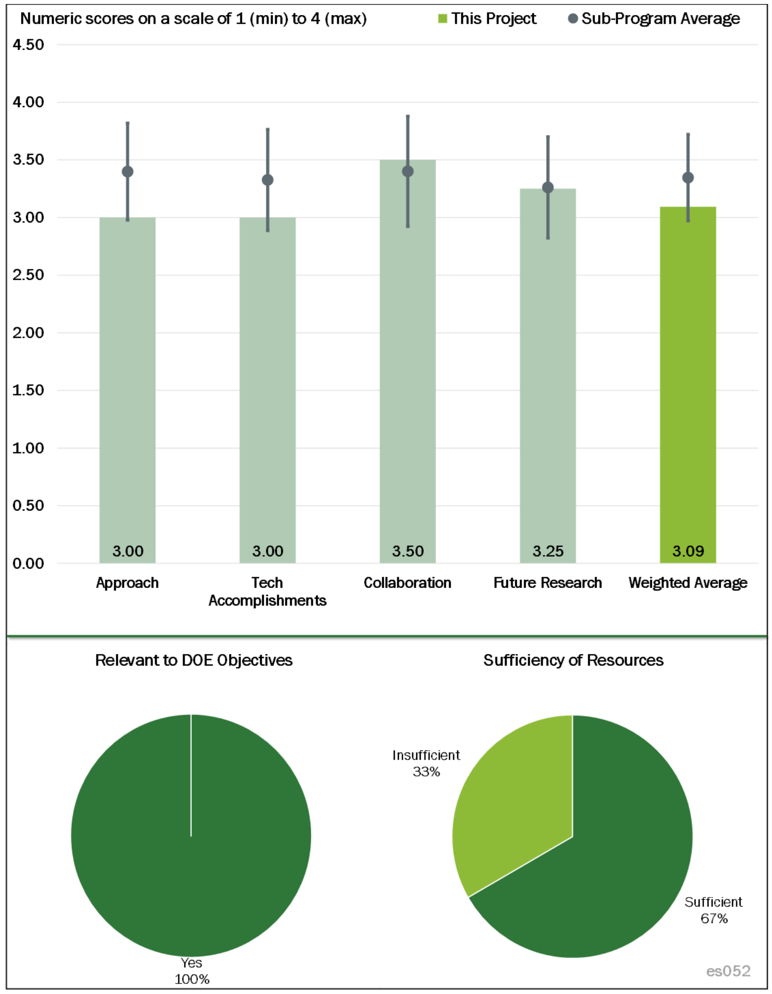

Figure 3-4 – Presentation Number: es052 Presentation Title: Design of High-Performance, High-Energy Cathode Materials Principal Investigator: Marca Doeff (Lawrence Berkeley National Laboratory)

Presenter

Marca Doeff, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer commented that the objective here is to develop high-performance cathode materials possessing high-voltage and high specific energies, based on NMC formulations synthesized by conventional and novel synthetic procedures (spray pyrolysis). The approach is to utilize various synchrotron (soft X-ray absorption spectroscopy [XAS], X-ray photoelectron spectroscopy [XPS], X-ray Raman, transmission X-ray microscopy [TXM]) and microscopy scanning transmission electron microscopy-electron energy loss spectroscopy [STEM-EELS]) techniques to characterize the bulk properties of the NMC cathodes with aliovalent titanium (Ti)-substitution, graded compositions, and surface coatings to understand the effects of the latter on the cathode performance.

Earlier in the project, it was shown that charging the NMC cathode to a high-voltage (4.7V) would create a reaction layer (cathode electrolyte interfacial [CEI]) due to surface reconstruction with metals being reduced on the surface. Also, it was shown from that there is an elemental composition gradient in an NMC made by spray pyrolysis, with less Ni on the surfaces of particles than in the bulk, which proved to be beneficial for cyclic stability.

The specific objectives in the current year are to understand the surface and bulk characteristics of the NMC622 cathode synthesized by spray pyrolysis and track the changes in oxygen (O_2) reactively, transitional metal ion valence in the bulk, and at the surface of the cathode material. These studies were expected to provide a detailed understanding of the effects of the synthetic method, cycling to (high) charge voltage, and the nature of delithiation on the surface and bulk properties of the cathode and its performance.

Reviewer 2:

The reviewer declared that overall relevance and objectives are adequately stated and technical barriers are properly addressed.

Reviewer 3:

The reviewer stated that it would help if the DOE PIs can have access to the best commercially used high-Ni materials for benchmarking; there are a number of commercial companies that have benefited from DOE funding and should be willing to assist.

Syntheses conditions and choice of precursors all affect the electrochemical performance. For example, pyrolysis seems to produce “gradient” type of materials and should be compared to those in the market.

In general, the project is well designed and is systematic in its approach; the right questions are being asked.

Reviewer 4:

The reviewer asserted that the characterization work in the project is well thought out and well executed—beautiful data from which strong conclusions can be made. Better use of these analytical results to suggest ways to improve the material needs to be made.

The reviewer had a concern that conclusions are specific to the synthesis method, which is not commercially relevant. This should be addressed.

Reviewer 5:

The reviewer pointed out that the design of the high-energy materials is not emphasized. The understanding of the electrochemical behavior of the NMC prepared by different methods has been investigated. The reviewer felt that the PI should first explore the effects of the chemical compositions of the NMC and also the effects of reaction conditions (such as rotational speed of atomizer, slurry flow rate, hot gas flow rate, and temperature, etc.) of the spray pyrolysis. Then, chemical, physical and electrochemical characterization should be conducted with the materials that have shown promising results of “low-cost, high energy density and good stability.”

Reviewer 6:

The reviewer commented that, unlike the title, the material design direction is not quite clear. Much effort was focused on characterization of well-studied materials.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

Overall, in the opinion of the reviewer, this project presents a good set of data on surface characteristics that could explain the high-voltage degradation phenomena of NMC622 material. However, because EV cells having NMC622 are currently under development, it would be very helpful to have benchmarking study results of commercial NMC622 materials to help battery and vehicle industries.

The reviewer asked several questions. The first question pertained to oxidized Ni ions, which are very sensitive to the surrounding environment, e.g., air exposure. The reviewer asked how much impact the PIs think the handling process (opening the cell, preparing the XAS sample, etc.) has on the surface nitrogen and oxygen state, and asked if there are any plans to do the XAS study *in situ*.

Next, the reviewer stated that it would be good to include synthesis condition of the NMC622 materials. The reviewer asked why the material synthesized by spray pyrolysis show lower nitrogen content at the surface than in bulk, and asked if it is controllable.

The reviewer wanted to know, compared to the conventional synthetic method of NMC622, which uses co-precipitation, and if the spray pyrolysis is cost competitive, does the state of charge (SOC) heterogeneity observed from the charged particles homogenize with time or does the inhomogeneity remains with time. Lastly, the reviewer asked what the impact is of the SOC inhomogeneity on the electrochemical performance.

Reviewer 2:

The reviewer noted that good progress has been made in understanding the bulk and surface properties of the NMC622 cathode made by spray pyrolysis. While the bulk structural changes during cycling to 4.7V are reversible, the surface conditions are found to be irreversible. The surface Ni and oxygen (with higher reactivity) behave differently from the bulk species, resulting in surface reconstruction and surface film formation. Interestingly, such surface reconstruction was not observed in the chemically delithiated samples, suggesting that the electrolyte presence is a contributory factor in the surface reconstruction.

There are other differences in the chemically delithiated samples from the conventional electrochemically delithiated samples. The spray pyrolysis method appears to reduce the surface concertation of nitrogen slightly, which is probably good in terms of cyclic stability. Nevertheless, a comprehensive comparison needs to be made between the conventional solid-state method and spray pyrolysis in terms of cathode microstructure, tap density, and the overall material and process costs. If spray pyrolysis is deemed to be superior, it would have been worthwhile to explore using it for NMC811, instead of undertaking chemical delithiation studies, which, the reviewed stated, are not as relevant.

Reviewer 3:

The reviewer said that some materials have been synthesized using the spray pyrolysis method. Core-shell structure has been found not to be good for NMC for this process. Nickel is already poor at the surface using the spray pyrolysis method. The study focused more on the instrumental analysis of the behavior of the NMC material during charge and discharge. Formation of CEI was found. The cut-off voltage was also found important in the stability of the NMC cathode. The results should be useful in guiding further study. The reviewer felt that the material synthesis part should have been conducted in order to obtain more results.

Reviewer 4:

The reviewer stated that the project is hitting its goals and targets, but it still needs to address “ways to improve” based on the learnings.

Reviewer 5:

Titanium and magnesium doping is well characterized and is being commercially used for the LCO materials. It might be worth studying it for the nitrogen-rich systems.

Reviewer 6:

The reviewer inquired as to whether there had been any comparison of NMC synthesized by spray pyrolysis and materials by other methods and asked what the advantages of spray pyrolysis are.

Other comments from this reviewer included stating that TXM may not be an appropriate tool for understanding the issues, particularly the electrochemical behavior of particles (while it is powerful for understanding morphologies, compositions, segregations, etc.) because the electrochemical behavior of particles depends on the local potential, extent of electrolyte wetting, and electronic particle connectivity.

NMC622 does not appear to show “excellent reversibility” because there is a high capacity loss in the first cycle.

Soft XAS data collected in various modes were presented and compared with reference spectra. Likely the reference data were collected in the bulk mode. Thus, the data may not be compared directly with Auger data or total yield mode data. Reference spectra collected in total electron yield (TEY) or Auger mode may be useful.

The reviewer said that it is difficult to believe that Mn is inactive in the voltage range of 2.5 - 4.7V. The reviewer asked about collecting more unambiguous Mn K-edge data using hard X-rays. While it is likely true that the surface Ni is less oxidized than the bulk Ni, the data do not support such a view because the spectra show the Ni^{3+} peak in the bulk looks larger than the surface Ni^{3+}. In addition, Ni_{3+} has a peak at the same position as the carbonate peak.

The carbonate peak (not necessarily LCO) disappears upon charging. The reviewer asked if it is due to carbon dioxide (CO_2) evolution or diffusion into the bulk.

The XANES spectrum for electrochemically charged NMC shows a low energy shift from 50% discharged condition. If the two spectra and the images are not switched, there must be significant electrochemical reaction delays depending on the location in the electrode and interparticle connectivity, which leads to severe non-uniform current distributions. In other words, the non-uniformity in the image can be artificial due to the electrode structure rather than the intrinsic material property.

XANES cannot be more accurate for SOC than coulometry. A SOC is the coulometry itself by definition. The reviewer pointed out that the XANES is measuring the extreme local charge distribution. If there is a slight non-uniformity throughout the electrode space including the way particles are electronically contacted, the reviewer underscored that the spot being probed does not reflect the whole electrode.

The reviewer urged not to forget that the spectrum data collected for chemical delithiation are static while the data during electrochemistry are dynamic. Further, this reviewer suggested collecting spectra for the electrode fully relaxed at open-circuit voltage after charging or discharging, if the project team needs reasonable spectra representing the SOC.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that there was outstanding, complicated coordination of work and characterization techniques with a broad variety of organizations and techniques. This project should serve as an example of coordination to others.

Reviewer 2:
The reviewer noted that this project consists of proper collaborators, and role of each collaborator is well defined.

Reviewer 3:
The reviewer said the project looks good.

Reviewer 4:
The reviewer indicated that there are good collaboration activities with several researchers in LBNL as well with external researchers: for example, with Stanford Synchrotron Radiation Lightsource (SSRL), with Brookhaven National Laboratory (BNL) in the basic studies on various NMC materials to understand the nature of the reconstructed surface layers, with NREL on the atomic layer deposition (ALD) coatings, and with University of California at Santa Barbara (UCSB) in the computational work. It is probably an appropriate time to collaborate with an industrial partner to assess the benefits of the spray-pyrolysis process.

Reviewer 5:
The reviewer observed that there were excellent collaborations with national laboratories and two universities on materials characterization. If industrial collaboration is available either from the materials synthesis or the materials application, that should be beneficial to the project.

Reviewer 6:
The reviewer recommended that a commercial partner supply samples for benchmarking.

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.

Reviewer 1:
The reviewer opined that the team needs to apply these wonderful characterization techniques to materials synthesized with commercially relevant processes.

Reviewer 2:
The reviewer remarked that it is great to explore NMC811 materials. The conditions in which the materials were obtained should give influential effect on their stability. The PI should explore the experimental conditions in addition to methods for the material synthesis.

Reviewer 3:
Appropriately, the reviewer stated, the future studies will largely focus on NMC811 to understand its surface as well as bulk properties in relation to the compositions already studied likewise (NMC532 and NMC622). These will include studies on the material synthesized using spray pyrolysis and also with different surface coatings and electrolytes (both will have substantial effect in the surface reconstruction). The future studies will also utilize collaborations with internal (at LBNL) and external researchers in exploring approaches toward making nitrogen-rich NMCs more robust.

These studies are consistent with the DOE goals of high specific energy, low-cost, and safe LIBs.

Reviewer 4:
The move to NMC811 is good, but the reviewer suggested that they try to get commercial (or semi-commercial) NMC811 materials and perform experiments as a reference. Also, it would be good to involve collaborators from the commercial sector. The reviewer would hesitate to call spray drying or pyrolysis novel synthesis, but hoped to see if the synthetic technique is viable in an economic sense. In this year's study, they showed the difference between surface and bulk. If the difference has a negative impact on electrochemical performance, the reviewer hoped they suggest ways to mitigate it.

Reviewer 5:
When assessing NMC811 material, the reviewer said that it is important to compare that to the NCA materials with the similar Ni and Co content.

Reviewer 6:
The reviewer stated that the future plan does not show any novel methods.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer commented that storage is very important for renewable energy supply. High density and low-cost, stable cathode materials are the key challenge for the next generation of LIBs. The success of this project will lead to some promising materials for EV battery fabrication. This will be beneficial for the displacement of petroleum consumption, especially in the transportation sector.

Reviewer 2:
The reviewer stated that for widespread use of EVs and PHEVs, it is imperative that LIBs be lightweight, compact, safe, and low-cost. The state-of-the-art materials are inadequate to fulfil these needs. High energy density electrode materials are required to improve the specific energy for Li-ion cells and thus increase the range for the vehicle and reduce overall cost for the battery. The state-of-the-art cathode materials provide capacities of only 170 mAh/g, about half of the capacities possible from the carbon anodes. We need to explore new cathode materials, which the present project is duly addressing.

Reviewer 3:
The reviewer opined that nitrogen-rich layered oxide is the only cathode material that can lead to high-energy cells for now. Developing and understanding the nature and drawbacks of nitrogen-rich layered oxide is quite relevant to the DOE goal.

Reviewer 4:
The reviewer noted that understanding nitrogen-rich materials is very important to ensure their safe commercial use and to establish and define quality requirements.

Reviewer 5:
The reviewer stated that any project focused on improvement of energy density supports DOE objectives.

Reviewer 6:
The reviewer responded, “Likely.”

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

Reviewer 1:
The reviewer thought that the time limitations of the characterization resources are not necessarily adequate, and it was a tribute to the team that they could accomplish this much given these limitations.

Reviewer 2:
The reviewer remarked that there was too much unnecessary characterization, and there may need to be more synthetic efforts of material surface modification rather than simple coating by ALD or molecular layer deposition (MLD).

Reviewer 3:
The reviewer said that the resources are adequate, if not slightly excessive for the scope of the project.

Reviewer 4:
The reviewer opined that the team obtained an excessive amount of characterization data. The reviewer wished to see better performance materials in terms of stability and energy density.

Presentation Number: es055
Presentation Title: NMR and MRI Studies of SEI, Dendrites, and Electrode Structures
Principal Investigator: Clare Grey (University of Cambridge

Presenter
Clare Grey, University of Cambridge

Reviewer Sample Size
A total of five reviewers evaluated this project.

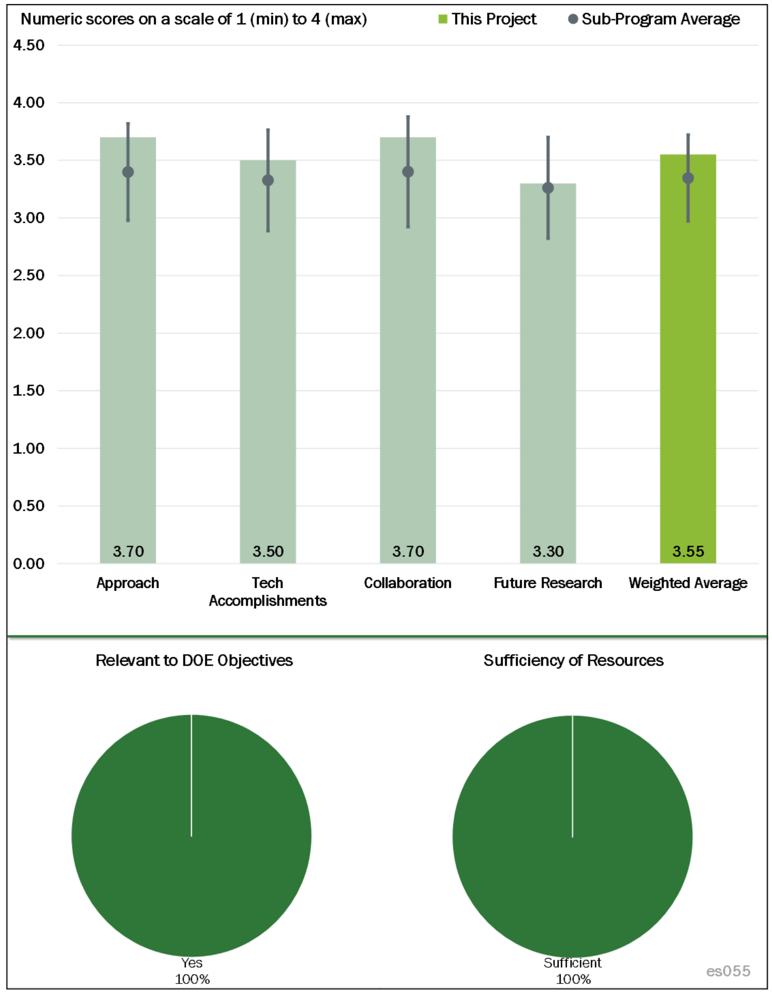

Figure 3-5 - Presentation Number: es055 Presentation Title: NMR and MRI Studies of SEI, Dendrites, and Electrode Structures Principal Investigator: Clare Grey (University of Cambridge)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer remarked that Clare Grey is a renowned expert in the field of nuclear magnetic resonance (NMR), and her group applied the unique technique to study Si solid electrolyte interface (SEI). The project team also used other techniques, such as X-ray paired distribution function (PDF) and tomography, in their studies. The project is well designed to address the barriers.

Reviewer 2:
The reviewer commented that developing a better understanding of the initial stages of SEI formation on Si anodes using modern characterization techniques including several spectroscopies is a very good objective that is fully addressed in this work. The second objective is associated with characterization of dendrite formation; although extremely challenging, that is also a key issue in the implementation of Li-metal based cells, which is being investigated by the team using magnetic resonance imaging (MRI) techniques. There are various complementary research collaborations in place.

Reviewer 3:
The reviewer stated that capacity fading and battery performance are correctly focused; experiments yield useful information of fluoroethylene carbonate and vinylene carbonate (FEC and vinylene carbonate [VC]) decomposition. Lithium dendrites and the behavior of the sodium anodes and cathodes are well designed. The reviewer complemented the team's results gotten with NMR on the study of SEI formation with new equipment at the University College London through P. Shearing. Complementary density functional theory (DFT) calculations yielded useful chemical shift trends, guiding the low sensitivity experiments and assignments.

Reviewer 4:

The reviewer found the use of NMR to measure numerous material properties that "should not" be available to NMR to be very creative.

Reviewer 5:

The reviewer acknowledged that the NMR approach is very solid as it provides interpretable data that disclose the chemical structure of each main component of the SEI for Si anodes, Li dendrites, and sodium dendrites. The MRI approach is innovative in establishing the growth of dendrites in three dimensions.

The use of only two additives to date was useful in determining the complicated structure of the SEI in these cases; however, it would be useful to examine other additives in a screening effort to bring focus to developing an improved electrolyte for Si anodes. This would include the presence of more than one additive in the electrolyte. The term "screening" is meant to apply to a less complete and time consuming study of each selected additive to try to select superior additives for more complete study. In other words, the reviewer suggested not trying to do an in-depth study unless the additive shows definite promise for a superior Si electrode.

The reviewer did not see the relevance of dendrite study on sodium anodes. The low melting point of sodium causes very severe safety problems and is unlikely to ever see development in a commercial cell. The reviewer asked why not study sodium in hard carbons or other anode concepts instead.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

With their advanced NMR and MRI techniques, they have characterized Si SEI, identified mechanisms of the growth of Li dendrites, and sodiation of tin anodes. The team is highly productive as shown by their publication records.

Reviewer 2:

The reviewer commented that it is interesting that the research is able to confirm the absence of fluorinated polymers that were debated for a long time. Low coulombic efficiency (CE) in electrolytes containing FEC was shown but not explained.

The reviewer said that It would be good to have summarized and extracted conclusions regarding the effect of the successful additives (VC and FEC) during cycling in Si anodes and the correspondence (if any) to the mechanical degradation of the anode due to volume expansion.

Regarding dendrite formation, the reviewer said that correlation with SEI and electrolyte composition is a great goal. Imaging of dendrite evolution is interesting, but a more quantitative assessment is needed. The reviewer noted that the effect of the presence of magnesium on the octahedral prismatic phase formation was not explained.

Reviewer 3:

After almost 50 years of measuring SEI composition, the reviewer could not think of how any of these measurements really helped build a better SEI. It was not obvious to the reviewer that the present work will be any different. Uniquely, however, Grey has proposed that a highly cross-linked organic layer can prevent transport of solvent to the Si surface. If this is true, it would provide a suggestion for how to make better SEI films. On the other hand, VC and FEC have similar performance. The reviewer questioned whether there is any evidence that VC forms such cross-linked films.

The dendrite work is extremely cool. The reviewer loved it.

Reviewer 4:

The reviewer asserted that the results on determining SEI components on Li and lithiated Si were excellent. Dendrite studies show promise, and the correlation of dendrite onset with the Sand equation is important in trying to unravel this complicated area. It also shows the importance of limiting the current density in any Li-metal cell to prevent the onset of dendrites. The reviewer would like to have seen any further in-depth studies limited to important additives or coatings as determined by screening studies or reports from other investigations because of the time required for such studies as noted by the PI.

Reviewer 5:

The reviewer stated that the team studied the SEI decomposition behavior in a Si anode in order to understand related interactions, finding two mechanisms for the dendritic growth (depending on the current intensity) and showing how sodium is distributed by a combination of phases. There were Interesting developments, such as the decomposition of the FEC and VC. Two mechanisms for microstructures growth were shown. It seems that more time will be required to reach the objectives.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

In order to study new materials to complete objective to design a stable SEI, the reviewer mentioned collaboration with the University of Rhode Island (Brett Lucht), who provided FEC and VC samples for the study of formation of SEI components, such as LiF, LCO, $Li_2C_2O_4$, and organic components. Also, the University of Illinois at Chicago, University of Cambridge, and Binghamton University provided materials. The X-ray tomography and NMR characterization were provided by University College London and NREL, respectively.

Reviewer 2:

The reviewer stated that this group has collaborations with many universities and national laboratories.

Reviewer 3:

The reviewer noted that the PI has extensive successful collaborations with Battery Materials Research (BMR) colleagues and other researchers using complementary techniques.

Reviewer 4:

The reviewer indicated that there was extensive collaboration, including work with tomography.

Reviewer 5:

The reviewer said that the corps of collaborators is very good from the experimental point of view with each contributing to the various techniques applied by the PI.

The reviewer would like to have seen a representative from the battery industry to make recommendations of other additives and what appears to be the most serious aspects of the probes under study.

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.

Reviewer 1:

The reviewer concluded that the study with the Si coatings as well as the investigation of the SEI in presence of coatings with NMR are very important because their results could avoid dendrite growth. Also, the study of sodium SEI could advance the development of this material alternative. In addition to the continued studies, the team should work on some high-risk, high-gain solutions.

Reviewer 2:
The reviewer observed that there were very clear statements for how the program will evolve.

Reviewer 3:
The reviewer commented that the proposed work includes logical continuations of the reported studies. The dendrite formation investigation and its ties to the SEI structure and stability could be particularly helpful.

Reviewer 4:
The reviewer stated that their future plans concentrated on NMR studies of Si and sodium SEI.

Reviewer 5:
The reviewer would like to have seen a stop to the work on sodium dendrites unless they are believed to be essential to understanding Li dendrites.

The list of additives to be used should be carefully determined to be sure there is time to study the most important ones.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said that SEI is one of the central problems in battery studies. Better understanding of the phenomena of SEI will help make better batteries.

Reviewer 2:
The reviewer stated that this project definitely supports the overall DOE objective of petroleum displacement by building fundamental understanding that will lead to better energy storage devices.

Reviewer 3:
The reviewer commented that the study is clearly relevant to the construction of higher energy density batteries of lower cost by use of Si or Li anodes.

Reviewer 4:
The reviewer said yes, if successful.

Reviewer 5:
The relevance of the sodium transport measurements to battery technology was not clear to the reviewer.

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

Reviewer 1:
The reviewer praised Clare Grey as a pioneer in NMR studies on battery materials. Her team, with wide collaboration with other groups, should be able to achieve the stated milestones in a timely fashion.

Reviewer 2:
The PI's laboratory is uniquely equipped to carry out these kinds of studies.

Reviewer 3:
The reviewer found the project to have good equipment.

Reviewer 4:
The reviewer remarked that resources seem sufficient.

Reviewer 5:

The reviewer noted that the experimental work that is the basis of this study requires substantial funding.

Presentation Number: es056
Presentation Title: Development of High-Energy Cathode Materials
Principal Investigator: Jason Zhang (Pacific Northwest National Laboratory)

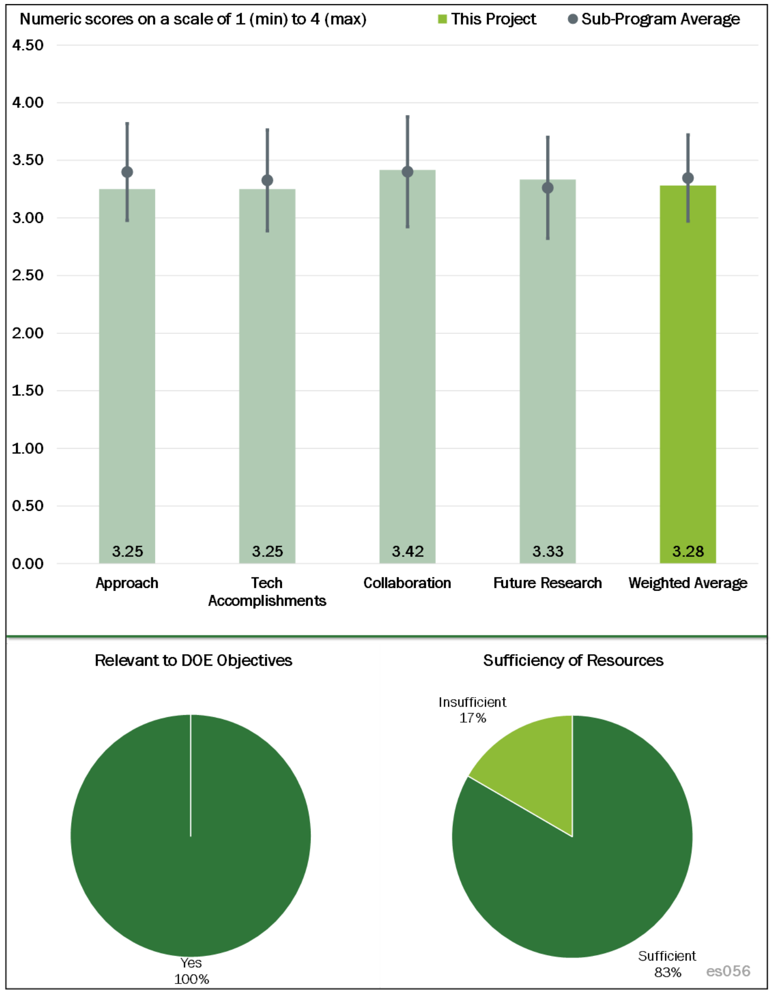

Figure 3-6 - Presentation Number: es056 Presentation Title: Development of High-Energy Cathode Materials Principal Investigator: Jason Zhang (Pacific Northwest National Laboratory)

Presenter

Jason Zhang, Pacific Northwest National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer stated that the objective here is to optimize the synthesis of Ni-rich NMC cathode materials using co-precipitation methods, to study the effects of lattice doping and solid electrolyte surface coating on the cyclic stability of these materials, and to understand the structural changes occurring therefrom. Various experimental conditions (flow rate, pH, concentrations of metal sulfates, etc.) were to be varied for the hydroxide precursors, which were calcined at different temperatures to get materials of high capacity and good cyclic stability.

This task is well focused on the Ni-rich NMC cathodes, expectedly the optimum choice among the cathode materials for high specific capacity and cycle life; it is also well designed and well integrated with the cathode development in other DOE laboratories, and the approach is feasible.

Reviewer 2:

According to the reviewer, the cathode materials have been optimized in terms of chemical composition and reaction conditions (annealing conditions). High energy density and very good stability were shown for Ni-rich (more than 0.6) materials annealed at 755°C and coated with lithium phosphate (Li_3PO_4). Physical, chemical, and electrochemical characterization has been carried out to elucidate the excellent performance of the materials obtained.

Reviewer 3:

The reviewer pronounced the approach of utilizing Ni-rich NMC to be excellent only if a high-voltage electrolyte is viable in cost and nontoxic.

Reviewer 4:
The reviewer suggested that using a design-of-experiments approach should help with determining syntheses optimization parameters as a function of cathode composition, including choice and amount of dopant and coating techniques.

Reviewer 5:
The reviewer noted that to achieve the DOE goal in energy density, the development and adoption of Ni-rich layered cathode is a good approach. However, there are downsides to Ni-rich layered cathodes, which are safety concerns.

It would have been more desirable if this project also considered material-level safety aspects.

Reviewer 6:
The reviewer said that the coating work looks interesting and promising, but questioned whether this had been done by others. The reviewer also thought that the team had given up on the doping too quickly. The reviewer would like to have seen more characterization work to support the statements about it being surface doped. The reviewer also asked if you need to re-optimize the calcination temperature as the composition changes.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer said that the milestones were achieved with excellent results either published or patented. The energy density is greater than200 mAh/g for pristine material. The surface coated cathode shows excellent stability at room temperature and is very good at high temperature. The experimental conditions as well as chemical compositions have been optimized. Additives in the electrolyte have been explored with some excellent results obtained.

Reviewer 2:
The reviewer commented that data from efforts of measuring the capacities with composition variation in NMC should be useful although it is expected that the capacity increases with Ni content.

The ALD-annealed material shows strikingly good performance. It needs to be further characterized by focusing on the nature of Li phosphate in the bulk of the secondary particles. Questions still arise. The reviewer asked is Li phosphate spread homogeneously in the particle, does it still remain as phosphate, have any other methods been tried, are there any other effective material, and what is the role of the phosphate.

When Ni is oxidized from 2 to 4, the Ni-O distance changes up to 0.2 angstrom, resulting in a huge lattice stress and particle degradation. The reviewer asked if $LiPO_4$ is a buffer preventing or redistributing the stress. This requires some *in situ* electron microscopy.

Reviewer 3:
The reviewer stated that good progress has been accomplished in synthesizing various Ni-rich NMC cathode materials and identifying the optimum composition as close to 811 ($LiNi_{0.76}Mn_{0.14}Co_{0.1}O_2$), which was shown to exhibit a good combination of capacity and stability consistent with the reported literature. Higher Ni content improves the cycle life but at reduced capacity.

It was demonstrated that surface cation doping has a limited effect in improving the cycling life, but coating with a solid electrolyte, such as Li_3PO_4, improves the cyclic stability, as has been reported with several coatings on layered oxide cathodes.

Washing the electrodes in water understandably affects the performance, which mandates ALD coating and may be expensive to adopt. Instead, there are several aqueous-based coatings that have been reported to be as effective, if not more, for enhancing the cyclic stability of metal oxides especially at high charge voltages.

Interestingly, there is not much reported here on the electrolyte variants, even though the Army Research Laboratory (ARL) has been listed as a collaborator for electrolytes. Also, as pointed out in the remaining challenges, thermal stability and hence safety of the Ni-rich NMC materials may be an issue, which may be mitigated by the surface coatings.

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

Reviewer 4:
The reviewer remarked that this project adopted a good approach for the precursor preparation. Regarding the optimum synthesis condition study, however, it would be expected, from study by a national laboratory like this, that not only "what" temperature is optimal but "why" the material at that temperature shows the best performance. The reviewer asked is it due to primary particle size, internal porosity, or surface transition metal state and oxygen activity. The reviewer asked does the material prepared at 775°C also show optimum performance in other aspects, such as impedance (and its growth) and thermal stability.

The solid electrolyte modification study shows meaningful results that could enhance cycling stability of Ni-rich cathode materials. What kind of phases really formed on the particle surface and at the grain boundaries should be explored. The reviewer believed that the industry has been looking into Ni-rich NMC cathode materials for EV applications, which means there must be commercial battery-grade Ni-rich materials. They should try to get those materials and use them as references.

Reviewer 5:
The reviewer stated that the project seems on target to meet its goals, and the novelty in this approach should be emphasized. The national laboratories should try some new things as the reviewer was not sure that this is new.

Reviewer 6:
The reviewer stated that there was good work on screening compositions of NMC materials, but there were no data on composition optimization. It was not clear what the effect of water-washing was as no conditions were presented. This is a widely used step in industry that leads to improved electrochemical performance. The reviewer asked if the material was dried after treatment. It also was not clear if ALD was performed on a powder or on the electrode. The reviewer asked what the temperature was of annealing. The solid electrolyte enhanced modification sounds overreaching as, according to Slide 11, the solid electrolyte diffuses into the bulk.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed that there was excellent use of resources and partners in the project, including the ALD work.

Reviewer 2:
The reviewer said that collaborations with other national laboratories in terms of materials characterization are important for the understanding of the excellent performance of the materials. The collaboration with a university in Canada leads to the excellent surface coating of LP, which gives much improved cycling performance. The collaboration with the U.S. Army laboratory is unique in its electrolyte development, which is very important for the Mn-containing, high-voltage cathode materials.

Reviewer 3:
The reviewer stated that there are good collaborations with several researchers within DOE (ANL and BNL) and elsewhere (Western University and ARL). It is probably appropriate to verify these results in full cells through collaborations with other DOE laboratories (ANL or ORNL) and examine the effects of different electrolytes and surface coatings.

Reviewer 4:
The reviewer praised the collaboration among the partners as well coordinated. It would be much better if they have industry partners, too.

Reviewer 5:
The reviewer commented that the collaboration look okay.

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.

Reviewer 1:
Of the four projects involving NMC cathode materials, the reviewer opined that this is the only one that proposes to tackle high temperature stability of the materials and fabricate the pouch cell. This is the key step toward real application of the materials synthesized. The reviewer wished the PI good luck and expressed confidence that more exciting results will be obtained next year.

Reviewer 2:
The reviewer recommended that *in situ* microscopy be coupled with energy dispersive spectroscopy (EDS) and agreed with testing the full cells in a pouch form.

Reviewer 3:
The future studies will involve continuation of the surface modification studies on the NMC811 cathode, the assessment of electrolyte additives to improve the interfacial stability, and subsequent characterization of the surface layer. Further, the reviewer proposed that the performance of the stabilized NMC be validated in full cells with suitable electrolytes. However, the reviewer commented that it would be more appropriate for this project to focus more on developing suitable coatings and electrolytes for the NMC811 materials in order to improve capacity and cyclic stability instead of the full pouch cells. The proposed studies are consistent with the DOE goals.

Reviewer 4:
The proposed future research looks good, and the reviewer especially liked the proposal of validation of the materials in full pouch cells. The reviewer said that it would be good if material level and cell level thermal stability study would be performed. Also, the reviewer suggested that the project obtain commercial (or semi-commercial) Ni-rich materials, make comparisons, and show the limitations of commercial materials and how those limitations could be overcome using the results in this project.

Reviewer 5:
The reviewer stated that half-cell data will indicate material stability on a large scale, but you really need full cell data to draw conclusions. The reviewer really would like to see more options on doping or coating going forward.

Reviewer 6:
The reviewer suggested that the project should include a thermal stability assessment of the studied compositions. No data were shown to demonstrate doping elements optimization mentioned in the approach; this might be a more practical approach versus ALD.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

For widespread use of EVs and PHEVs, the reviewer noted that it is imperative that LIBs be lightweight, compact, safe, and low-cost. The state-of-the-art materials are inadequate to fulfil these needs. High energy density electrode materials are required to improve the specific energy for Li-ion cells and thus increase the range for the vehicle and reduce overall cost for the battery. The state-of-the-art cathode materials are inadequate and provide capacities of only 170 mAh/g, about half of the capacities possible from the carbon anodes.

New high-capacity and low-cost cathode materials are desired to meet the DOE goals, which this project has been addressing.

Reviewer 2:

The reviewer commented that NMC is an important cathode material for high-energy LIB manufacturing. Such batteries are essential for energy storage for renewable energy supply and also as a power supply for EVs in transportation. This will displace petroleum in its application.

Reviewer 3:

The reviewer stated that any efforts to improve cell energy density support the overall DOE objectives.

Reviewer 4:

The reviewer remarked that enhancing the current EV cell energy density critically depends on cathode materials, given that high capacity anode material (e.g., Si-based) have a long way to go.

Reviewer 5:

The reviewer said yes.

Reviewer 6:

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

Reviewer 1:

The results obtained meet the objectives in timely manner. Milestones have been achieved with excellent performance Ni-rich NMC obtained with chemically and operational conditionally optimized conditions.

Reviewer 2:

The reviewer said that the resources are adequate for the scope of the project.

Reviewer 3:

The reviewer stated that a good amount of work has been completed for the funding level of the project, it takes a lot of effort to synthesize different materials and optimize calcination temperature, and more resources would allow exploration of a wider space of compositions and coatings.

Reviewer 4:

The reviewer pronounced that the project looks good.

Presentation Number: es059
Presentation Title: Advanced *In Situ* Diagnostic Techniques for Battery Materials
Principal Investigator: Xiao-Qing Yang (Brookhaven National Laboratory)

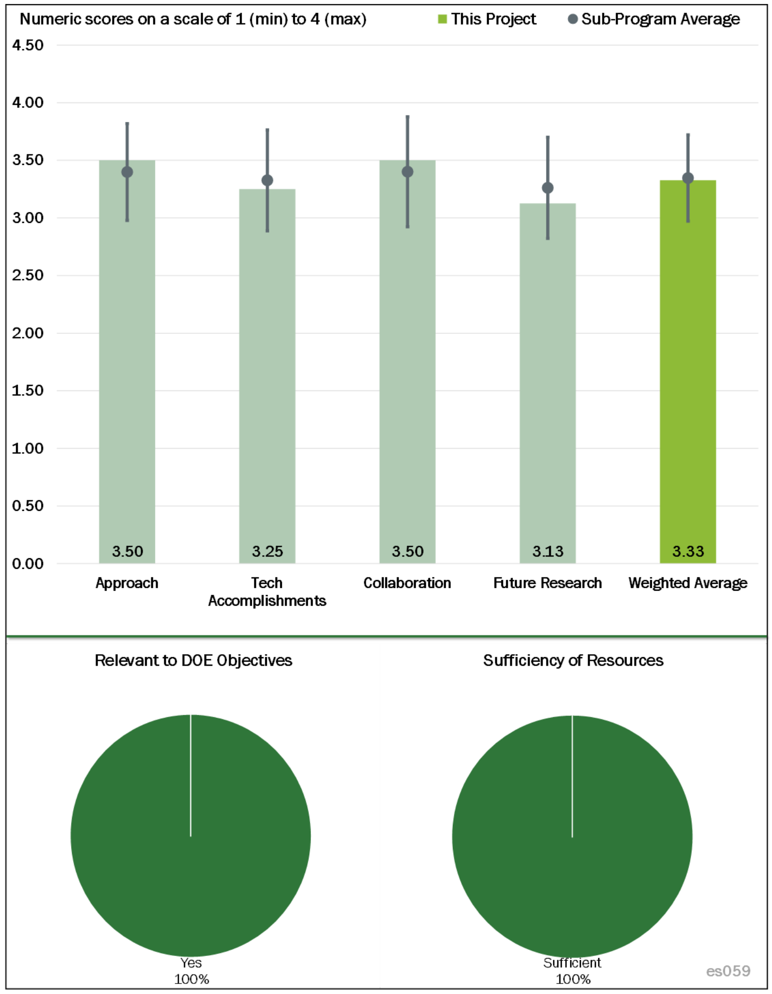

Figure 3-7 - Presentation Number: es059 Presentation Title: Advanced *In Situ* Diagnostic Techniques for Battery Materials Principal Investigator: Xiao-Qing Yang (Brookhaven National Laboratory)

Presenter

Xiao-Qing Yang, Brookhaven National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer commented that the team has access to top instrumentation at BNL and other national laboratories. A good combination of experiments has been selected to address most of the technical barriers.

Reviewer 2:

The reviewer said that the combination of techniques leads to unique sets of structural information under conditions reasonably close to real cell results. Even in unusual situations, such as the initial discharging of already discharged materials such as $LiRu_{0.5}Mn_{0.5}O_2$, structure results are obtainable. The project continues this type of important analysis of LIB components.

Reviewer 3:

The reviewer stated that it looks like a successful approach to overcome the technical barriers. Barriers with which they had to deal were to understand the structural changes of cathode materials producing voltage and capacity fading during high-rate charge and discharge cycles. They used PDF techniques to study the effects of multiple cycling for $Li_2Ru_{0.5}Mn_{0.5}O_3$ (lithium- and manganese-rich [LMR]) cathode material with and without pre-lithiation, HRTEM, and TXM to obtain multiple dimensional mapping of new cathode material. Another barrier they had to deal with was to develop a diagnostics study aimed to improve the safety characteristics of batteries; they used time resolved X-ray diffraction and mass spectroscopy, together with *in situ* soft and hard X-ray absorption spectroscopy (XAS) during heating to study the thermal stability of the electrode materials.

In 2016 the Li Ni Mn spinel-lithium manganese nickel oxide (LMNO) material was analyzed due to its good capacity but presented problems of thermal instability; now in the work of 2017, they are analyzing the LMR material that yields greater capacity when pre-lithiated, but at the same time the pre-lithiation increases the loss of voltage due to the microstructures that are formed. At this point the plan of study is not very clear, but the reviewer agreed that different materials with high energy density are being analyzed.

According to the results, the project is feasible and provides a depth of understanding of materials problems to get high energy density. In this case for the LMR material, they have to finish the studies that are pending to determine how to compensate for the loss of voltage when the pre-lithiation process is performed.

This project focuses on the study of new materials for high energy density cathodes; however, it can be integrated as part of the larger study that is being done in the same way for new materials for anodes and electrolytes and their interactions.

Reviewer 4:

The reviewer enthused that the demonstration was a tour de force that combined many different diagnostics. It was impressive that they are able to collect so much data. The reviewer was not sure that it makes sense to claim that these studies will lead to lower cost batteries.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer said that regarding the objective of DOE to reduce the production cost of PHEV batteries by having a long calendar and cycle life, the project has made considerable progress in the analysis of materials of high energy density, especially LMR materials. The project has obtained results, such as the structural behavior of the material during charge and discharge, that allow the community to have a better idea of how to find the right material for electrodes and especially for the high energy density cathode, which we know has problems of thermal instability. This reviewer commented that with the results obtained in this work, the spinel phase is verified for the pre-lithiated LMR sample along with the loss of its crystallinity via volume expansion at pre-lithiation, which allows the material to form vacancies by releasing oxygen easily.

Reviewer 2:

The reviewer noted that the technical accomplishments are excellent even with the limitations of beam time at BNL due to the new, high resolution, high power line.

Reviewer 3:

The reviewer remarked that voltage fade studies of cathode materials containing excess Li were well characterized using various techniques. It was not clear how the phenomena may depend on particle size and shape, which may alter the kinetics of phase transformation. The reviewer added that there was not much discussion given to the safety aspects.

Reviewer 4:

The reviewer praised the enormous and impressive compilation of data (5 dimensional!), so in this sense, the reviewer saw that great progress has been made. But, the reviewer did not see any new insights yet and did not see how new insights will be forthcoming. The main conclusion so far is that defective material does not perform as well as more perfect material, which is already known.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer stated that the use of collaborators was impressive.

Reviewer 2:

The reviewer commented that the overall collaboration is very good. The team should also increase collaborations with battery companies.

Reviewer 3:

The reviewer noted that collaborations are generally excellent, but it is not clear how the industrial partner, JCI, contributes to the effort. This is important because it can focus some of the work to industrially important problems and materials.

Reviewer 4:

The reviewer pointed out the great collaboration with several laboratories and institutions to obtain necessary knowledge to perform certain experiments, especially those working with X-rays because they require a whole process of preparation and tuning in each test. Among the institutions are: the Stanford Linear Accelerator Center (SLAC) to perform TXM, BNL to perform Z-contrast STEM, and the National Synchrotron Light Source II (NSLSII) to perform X-ray powder diffraction (XPD) and hard X-ray nano-probe (HXN) beamlines. However, it is advisable to also get collaborators in the industry in order to have different points of view to make the project progress more significant yet.

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.

Reviewer 1:

The reviewer noted that it is important to continue to develop the TXM work, including STEM studies to further understanding of reaction paths of cathode materials.

Also, the XFM method development will give further structural detail to the reactions in the cathode.

Reviewer 2:

The reviewer would like to have seen a clear pathway to gaining new insights. There is an extraordinary amount of information, and the reviewer suggested that using statistical methods might allow an unlocking of subtle “quantitative” relationships between measured properties and battery durability.

Reviewer 3:

The reviewer pointed out the great collaboration with several laboratories and institutions to obtain necessary knowledge to perform certain experiments, especially those working with X-rays because they require a whole process of preparation and tuning in each test: among them, SLAC to perform TXM, BNL to perform Z-contrast STEM, and NSLSII to perform XPD and HXN beamlines. However, it is advisable to also get collaborators in the industry in order to have different points of view to make the project progress more significant yet.

Reviewer 4:

The reviewer stated that the proposed plan was vague and had no focus.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

Yes it does. Characterization of materials is an important aspect in the development of advanced energy storage technology.

Reviewer 2:
The project fully supports DOE objectives

Reviewer 3:
The reviewer responded, "Yes." They analyze a high-voltage cathode (LMR material), which features greater capacity when a pre-lithiation process is carried out. However, due to the loss of voltage during charge, discharge cycles, and the release of oxygen, it is still not a cathode suitable for EVs. However, it is helping anyway to understand better what the effects of micro-structural defects are so we will soon find an LMR material with a good capacity whose voltage loss will not be too large.

Reviewer 4:
The reviewer opined yes, but said that the connection is at present very tenuous.

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

Reviewer 1:
The high cost of maintaining the very sophisticated instrumentation justifies the budget of this and other projects.

Reviewer 2:
The resources are adequate to achieve the milestones in time. Because this work will continue and complete the PDF, STEM, and TXM studies of $Li_2Ru_{0.5}Mn_{0.5}O_3$, as well as develop and apply XFM techniques for battery material studies, the present work already underway with sufficient background will help to perform research with the synchrotron effectively.

Reviewer 3:
The reviewer said that more beam time at BNL would be helpful.

Reviewer 4:
The reviewer pointed out that impressive resources are required for such an ambitious project.

Presentation Number: es085
Presentation Title: Interfacial Processes in EES Systems Advanced Diagnostics
Principal Investigator: Robert Kostecki (Lawrence Berkeley National Laboratory)

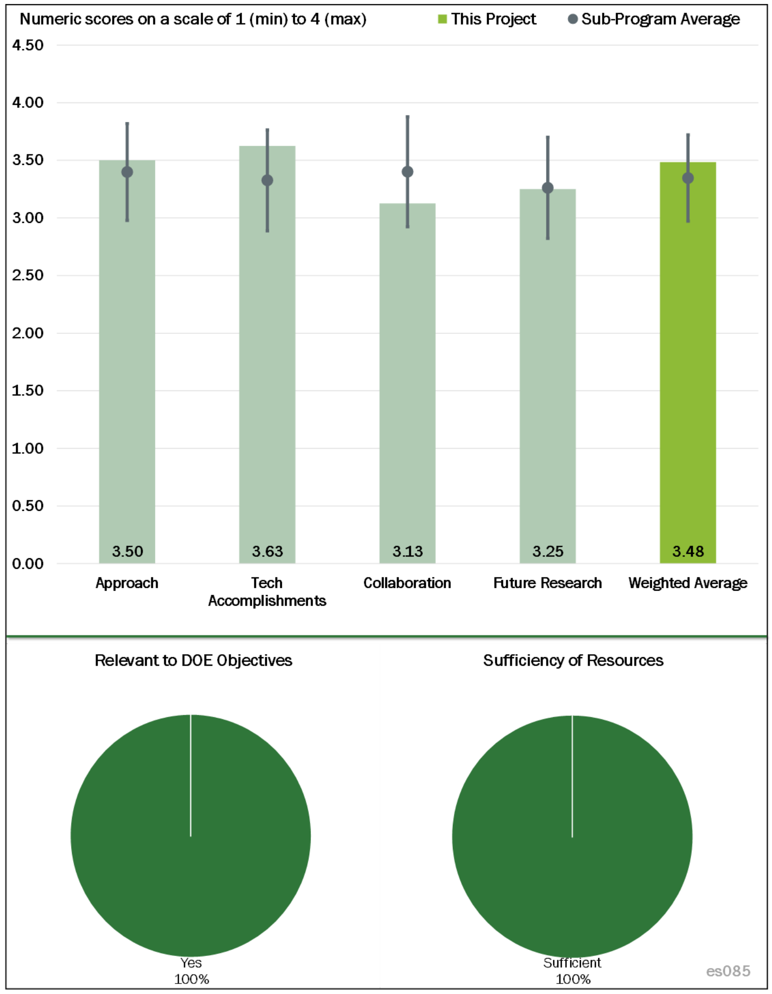

Figure 3-8 - Presentation Number: es085 Presentation Title: Interfacial Processes in EES Systems Advanced Diagnostics Principal Investigator: Robert Kostecki (Lawrence Berkeley National Laboratory)

Presenter

Robert Kostecki, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer commented that the project is well focused and is part of larger efforts involving sophisticated characterization methods of interfacial materials and phenomena.

Reviewer 2:

The reviewer stated that the approach is well designed to answer the difficult questions about the reactions on the surface of active cathode materials.

In particular, the X-ray methods combined with Raman spectroscopy are very powerful.

Reviewer 3:

The reviewer noted that the LBNL group led by Robert Kostecki combined an array of advanced characterization techniques (optical, X-ray, and electron) to investigate the structure and function relation of electrode materials in order to better understand the mechanism of their capacity fading.

Reviewer 4:

The reviewer observed that the barriers of low energy and power density, short calendar and cycle lifetimes, and high impedance are being approached by more rational than empirical diagnostic techniques focusing on the kinetic studies at the interface of NMC electrodes with the electrolyte. The project includes well-organized use of state-of-the-art with electrochemical methods. The project achieves success on shedding light on mechanisms of interfacial phenomena and surface reconstruction effects on impedances. Results can be integrated with others developing ALD to coat NMC to get a stable NMC Li-ion cell.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The progress in this period has been very good. The identification of the surface reconstruction layer (SRL) and the suggestions of its chemical composition are excellent steps.

The impedance studies of pristine NMC and NMC with pre-reconstruction of the surface give intriguing results on cycling. If this can be replicated and applied to other cathode materials (particularly NCA, LCO, and lithium-manganese oxide [LMO]) this could be a major finding for LIB technology.

Reviewer 2:
According to the reviewer, the LBNL group has done a great job in investigating the effect of surface reconstruction in NMC electrodes. The artificial SRL seems to have improved the long term cycling properties of NMC. It is still not clear why the artificial SRL acts differently from that formed during charge-discharge cycling, especially because they differ only at later cycles and only in the 2-4.5V range.

Reviewer 3:
The reviewer commented that identification of surface reactivity, film formation, and surface reconstruction at the cathode and electrolyte interface are definite accomplishments of this project.

It would be good to link the characterized interfacial phenomena to achieving kinetic control of the cathode reactivity.

Reviewer 4:
The reviewer commented that the effects of surface reconstruction in NMCs based on impedance spectroscopy perhaps need to be extended to other Ni-rich NMCs besides the 5:3:2 to make a more general conclusion that the performance of these materials is upgraded with an artificial layer (NMC/R). There is no information other than that 5:3:2 NMCs were tested.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that the project has a large and strong collaboration. The initial (early) calculations to understand the formation of the surface reconstruction as well as the initial NMC structure and composite electrode previously tested by M. Doeff (LBNL) and C. Ban (NREL). The XAS-TEY experiments for this project were developed in collaboration with M. Doeff (LBNL) and Liang Zhang (Advanced Light Source at LBNL). These experiments help support the idea that an artificial reconstruction layer improves the cell performance; thus, these collaborations and interactions require a concerted effort such that different results from different experimental techniques lead to the development of high energy density materials. In addition, they worked with M. Marcus (LBNL) performing XANES experiments and data analysis. Earlier electrode materials were supplied by V. Battaglia (LBNL) and Y. Fu (LBNL), but no information on the new ones is available.

Reviewer 2:
The reviewer stated that this group has wide collaborations with other institutes.

Reviewer 3:
The reviewer said that the project is well integrated with others at LBNL, but there is some degree of duplication with Doeff's presentation.

Collaborations with other institutions and battery companies, although mentioned, were not explicitly explained.

Reviewer 4:
The reviewer mentioned that collaboration with other academic institutions is excellent.

The collaboration with industry could be improved, especially with regard to adding a battery manufacturer. Also, it is not clear what role Umicore plays other than supplying material. They could be helpful in suggesting other, more efficient methods of forming the reconstructed surface.

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.

Reviewer 1:
The reviewer commented that the group has a well-defined plan for future work. It is important to study the crosstalk and quantify each side reaction in the electrode during the cycling to understand the SRL effects.

Reviewer 2:
The reviewer commented that the proposed future research seems to be well organized and focused on the study of the reactions in a more localized way, implying the development of new experimental techniques. All this is in accord and coherent to obtain a progressive approach to the present state of the project; however, the reviewer pointed out for future work the following: First, as indicated before, because the impedance work is about a 5:3:2 concentration, it should be good to try with another Ni-rich concentration to check if similar or even better behavior using the artificial reconstruction layer is obtained. Next, the thickness of the artificial reconstruction layer was made similar to the one that evolves from electrochemical charging and discharging; however, it could be good to know what happens for different ones. Lastly, although there were very early collaborations, (2013 and earlier) with theoretical groups, it is important to establish intense collaborations with a theoretical-computational multi-scale team able to interact and provide feedback to the experimental approach from the atomistic to the mesoscopic scales. That would be of great benefit to the energy storage community and most likely will accelerate the discovery.

Reviewer 3:
The reviewer said that the proposed future work is very general.

The reviewer felt that the outstanding result of reduced impedance growth of surface pre-reconstruction should be specifically followed up and expanded to other materials if it can be replicated for NMC.

Reviewer 4:
The reviewer stated that the proposed work is vaguely described. More emphasis on the dynamic aspects of the interfacial phenomena is needed in order to achieve the objective of kinetic control. More specific plans should be indicated.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer responded yes. One of the main obstacles to developing a high-energy density battery is the reactions that occur at interfaces. For this reason, the study of these interfaces is vital to proposing solutions to eliminate or considerably reduce obstacles.

Because this project shows the reduction of reactions occurring on NMC and electrolyte interfaces, NMC is perhaps a suitable material for Li-ion cells for PHEVs and EVs. NMC improves the performance of these type of batteries, and thus petroleum consumption will be reduced.

Reviewer 2:
The reviewer stated that the project aims to improve the inadequate LIB energy and power density and calendar and cycle lifetimes for PHEV and EV applications.

Reviewer 3:
The reviewer pointed out that characterization of interfacial phenomena is vital to the development of better energy storage materials, which would eventually be a pillar for petroleum displacement.

Reviewer 4:
The reviewer said that an understanding of cathode operation and fading is of vital importance.

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 with wide collaboration with multiple institutes and the strong research capabilities of LBNL, the team has adequate resource to achieve their goals.

Reviewer 2:
The reviewer remarked that considering the high cost of highly sophisticated equipment maintenance, the resources appear reasonable.

Reviewer 3:
The reviewer noted that $440,000 per year directly supporting the group seems sufficient although no number of supported researchers is reported.

Presentation Number: es091
Presentation Title: Predicting and Understanding Novel Electrode Materials From First-Principles
Principal Investigator: Kristin Persson (Lawrence Berkeley National Laboratory)

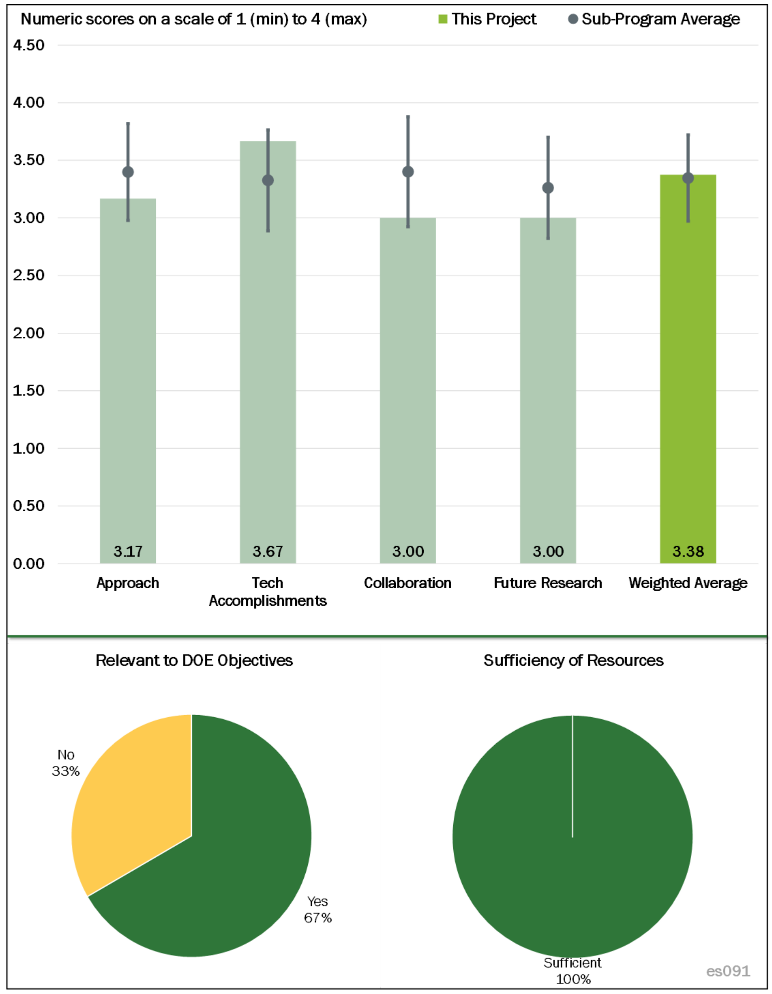

Figure 3-9 - Presentation Number: es091 Presentation Title: Predicting and Understanding Novel Electrode Materials From First-Principles Principal Investigator: Kristin Persson (Lawrence Berkeley National Laboratory)

Presenter
Kristin Persson, Lawrence Berkeley National Laboratory

Reviewer Sample Size
A total of three reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer understood the logic of using Li_2MnO_3 as a worst-case scenario, and in some cases that may be the best approach. However, the reviewer noted that earlier theoretical studies indicate that Li diffusion in the bulk material is relatively fast, which is in contradiction to many experimental studies. If the transport in the bulk regions is good, then one may naturally assume that the transition regions may be a problem. Eliminating these regions may be overlooking an issue, and in fact one result of this study is that the surface phenomena are an issue.

Reviewer 2:
The reviewer remarked that this computational modeling approach has been pursued for quite a length of time, yet the fundamental approach has not been effectively solving some of the technical barriers, including stabilities of the energy materials, kinetic pathways for more in-depth understanding of the polarization from surface to the solid bulk, and finding a more energetic solution of new chemistries that can provide higher energy content or better kinetics to deliver energy to power. A fundamental breakthrough on the modeling approach from first principles seems necessary. The reviewer encouraged the investigator(s) to collaborate with more experimentalists and theorists to develop a more detailed model framework to overcome the current barriers within the model for more fruitful outcomes that can benefit the research community.

Reviewer 3:
The reviewer commented that extensive modeling work was performed to systematically screen surface doping atoms that can increase oxygen retention on the surface of Li_2MnO_3 and asked if there is any plan to valid the model prediction experimentally.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer found the PI's scientific abilities and techniques to be of the highest quality and the work is excellent. The reviewer found the PI's willingness to propose solutions to improve performance very impressive.

Reviewer 2:

The reviewer said that the predicted surface dopants are a nice accomplishment that provided new material design directions on how to stabilize high-capacity Li-excess NMC cathode materials. This is highly relevant and important for meeting DOE energy density goals.

Reviewer 3:

The reviewer stated that it seems clear that the interfacial properties of the cathode materials in relevance to the bulk, the interactions with the electrolyte species (including solid electrolyte interphase), and the surface coating materials and their migration into the near surface region or dissolution are very complicated phenomena even for experimentalists to gain sufficient understanding from the experimental results. The challenge is much higher for modeling efforts. It is not clear if this first-principles approach is the right approach to deal with this technical area of interest or not. Without a clear justification why this approach will provide a reasonable outcome, it is almost impossible to see if a goal can be established with a reasonable expectation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer found that good collaborations exist.

Reviewer 2:

The reviewer pointed out that collaboration within LBNL is fine, but there are no obvious collaborations outside the laboratory.

Reviewer 3:

The collaboration seems limited within the Berkeley community between LBNL and the University of California at Berkeley (UCB). More external collaboration with other theorists and experimentalists is encouraged to gain access to a broader research community for inputs and reliable data to validate the approach.

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.

Reviewer 1:

According to the reviewer, the proposed work is a good extension of the present results. If the focus is continuing with Li- and Mn-rich materials, then the reviewer would prefer to have seen some effort to examine LMR-NMC materials.

Reviewer 2:

The reviewer stated that surface coating and experimental work related to the characterization of any effects is quite difficult to reproduce, and that many of these effects might not be straight to chemical nature. It is not comprehensive how this first-principles approach will resolve these possible variations that may render inconclusive results to conform to a universal understanding in first principles. Defects and amorphous state(s) could be even more challenging to model. It is not clear how these issues will be resolved and modeled with sufficient clarity and fidelity.

Reviewer 3:

The reviewer said that it will be useful to have some strategy on how to compare experiments at multiple places, for example which surface is more stable in terms of oxygen retention.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer remarked that this research is very much related to petroleum displacement as it will help to enable higher energy batteries.

Reviewer 2:

The reviewer said that the work is relevant.

Reviewer 3:

The reviewer acknowledged that although in general, the battery technology is intended to reduce reliance on fossil fuels, all research activities supporting a better battery design could contribute to that goal. It is not clear though how the direct relevance of this project to support that goal can be qualified or quantified through this project. If a more tangible outcome can be identified, the relevance would be clear.

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 are sufficient.

Reviewer 2:

The reviewer observed that the resources needed for the project probably rely more on the quality of the data available for validation. It is difficult to read how much resources are needed for this project in general.

Presentation Number: es106
Presentation Title: High-Capacity Multi-Lithium Oxide Cathodes and Oxygen Stability
Principal Investigator: Jagjit Nanda (Oak Ridge National Laboratory)

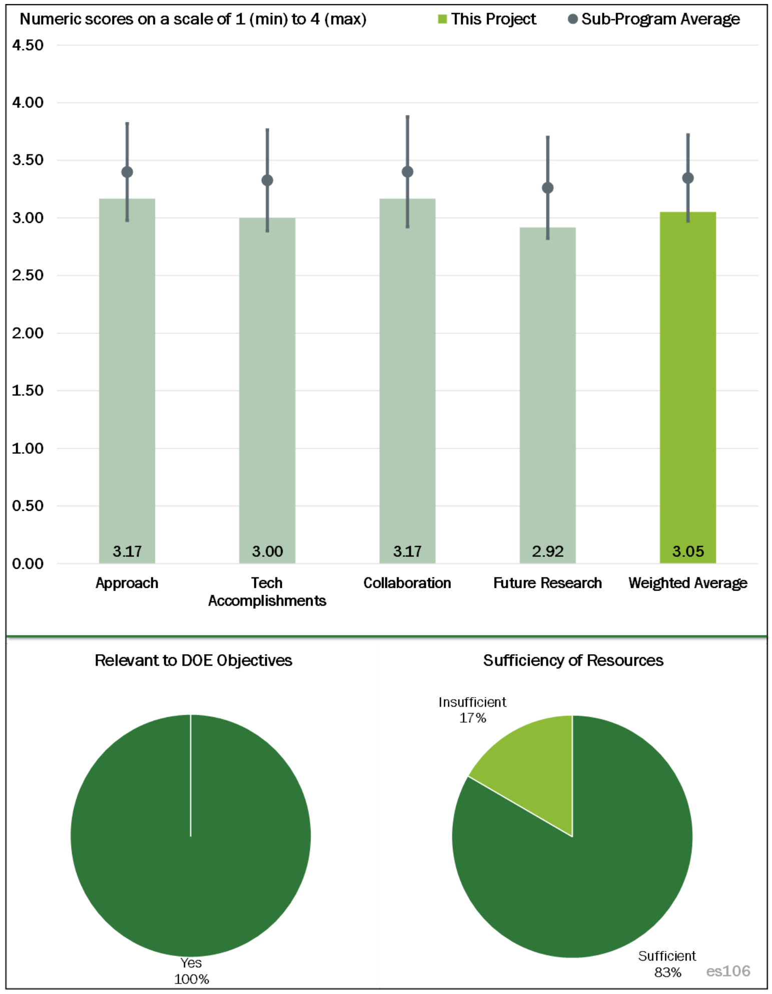

Figure 3-10 – Presentation Number: es106 Presentation Title: High-Capacity Multi-Lithium Oxide Cathodes and Oxygen Stability Principal Investigator: Jagjit Nanda (Oak Ridge National Laboratory)

Presenter

Jagjit Nanda, Oak Ridge National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer commented that the project offers interesting insights into Li-rich systems and is excellent diagnostic work.

Reviewer 2:

The reviewer found the approach to be solid and addresses technical barriers key to the advancement of LIBs. Cathode materials that can cycle more than one Li^+ per transition metal could allow DOE to meet its energy density goals (500 mAh/g). The team will synthesize promising high-voltage, high-capacity cathodes using computational analysis. This will be followed by cycling cells and spectroscopic diagnostic and analytical techniques to identify chemical and structural changes that prevent cells from achieving high capacity and long cycle life. The plan to develop methods to stop lattice oxygen loss and improve cathode structural stability is highly relevant.

Reviewer 3:

The reviewer pointed out that adopting multivalent metals for higher capacities is reasonable as long as the voltage is low enough not to decompose or continuously react with electrolytes.

Reviewer 4:

The reviewer acknowledged that, for improving the specific energy of the cathode materials in Li-ion cells and thus achieving cell level specific energies of 400-500 Wh/kg, the Ni-rich NMC cathodes and NMC cathodes with concentration gradient (Mn-rich on the surface and Ni-rich in the core) are the most likely candidates. These materials cathodes sustain either oxygen loss or redox behavior during cycling, which results in irreversible capacity or structural changes.

The objectives here are to understand the oxygen activity and its role in the redox processes, the loss of oxygen, and the resultant structural changes in the high-voltage and high-capacity cathodes. The approach involves developing high-voltage, high-capacity oxide cathodes with suitable anionic substitution and advanced coatings for interfacial stability and understanding the interface and bulk structure using various microscopic and spectroscopic techniques. Specific materials studied here include Ni-rich $Li_2Cu_xNi_{1-x}O_2$ and $LiMoO_3$, which has improved lattice oxygen stability for Li-excess composite high-voltage cathodes.

The objective was to access the higher oxidation states of $Cu^{2+/3+}$and $Ni^{3+/4+}$, but the oxygen evolution presented this from happening. The synthetic methods yielded either surface impurities or local inhomogeneities. The idea of assessing oxygen redox activity in the high-voltage cathodes is highly relevant, but the $LiMoO_3$ may not be the right material due to its low capacity and conversion to amorphous state after the first cycle.

Reviewer 5:

The reviewer stated that the project was a thorough, multi-faceted approach to improved materials and generated a lot of data to suggest improved materials. However, the reviewer would like to have seen a pathway or strategy toward using the learnings for future work. The reviewer thought the conclusion on disordered materials is a good one, but asked what was learned here that would help that effort beyond what has already been published on these types of materials.

Reviewer 6:

To achieve higher capacity from a given cathode material, charging the cathode to higher voltage is considered a straightforward and effective way. However, in addition to the electrochemical stability issue of the electrolyte system, surface instability of oxygen is a critical issue, which significantly affects structural stability and cycling performance of the cathode upon repeated high-voltage cycle as well as the inducement of safety issues. In these respects, understanding oxygen stability of cathode materials at high-voltages is highly needed.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer commented about the excellent progress achieved this past year. A paper was published in *Chemistry of Materials* describing the mechanisms of electrochemical activity and degradation of $Li_2Cu_xNi_{1-x}O_2$ cathodes. This information will help guide the team to identify more stable, high-performance cathode materials.

Reviewer 2:

The reviewer suggested that reasonably good progress has been made in determining the chemical and structural changes that occur in $Li_2Cu_{0.5}Ni_{0.5}O_2$ using *in situ* TXM-XANES. There is a shift in the copper (Cu) and Ni edge to lower energies at greater than or equal to 4V, though it is not clear what this may be attributed to (not Cu^{+2} to Cu^{+3}). It is also surprising that oxygen evolution starts occurring at 3.9V, though we do not observe this in the conventional cathodes (LCO, nickel cobalt oxide, NCA, or even NMC) at this voltage. The reviewer wondered if the presence of Cu was catalyzing O_2 evolution.

Detailed studies have been made to understand the electrochemical activity and degradation of $Li_2Cu_xNi_{1-x}O_2$ cathodes using a combination of X-ray and neutron diffraction, *in situ* Raman spectroscopy, electrochemistry, gas evolution experiments, and transmission electron microscopy (TEM). The results, however are not quite encouraging in terms of utilizing the second Li from this material.

The cyclic stability of $Li_2Cu_xNi_{1-x}O_2$ has been marginally improved as shown in previous report, but the (low) voltage profile and low capacity are not attractive. Further, fairly good efforts were made in synthesizing and characterizing the molybdenum analogue of Li_2MnO_3 with greater oxygen stability through electrochemistry, XRD, and Raman. But, the initial results do not hold promise for this to provide much insight in the oxygen redox behavior due to its low capacity, low efficiency (suggesting O_2 loss), and conversion to an amorphous state.

Overall, the progress is good and directed toward DOE goals.

Reviewer 3:

This project studied interesting oxide compounds of Li-rich Li_2MO_3 and Li_2MO_2. However, the reviewer could not see what merits these types of oxides have in developing high energy cathode materials.

At first sight, these oxides look interesting because they contain two Li per transition metal, but they cannot cycle reversibly once delithiated over a certain degree. Also, in developing high energy cathodes, one should also consider redox voltage, not only capacity. According to the cycle results, the average redox voltages are too low so that the overall energy they deliver is not high enough although the gravimetric capacity seems high.

From a materials science perspective, the proposed or studied oxides are interesting, but from high energy battery development perspectives, they are not attractive.

Some analytic tools they used are good, but the reviewer did not see significant differentiation from other projects.

Reviewer 4:

The reviewer commented that it is important to consider that different Li-salt precursors might be required when the Ni content varies; that could the main reason for the poor performance of low versus high-Ni content materials.

Reviewer 5:

The reviewer stated that the Li extraction associated with Cu redox changes requires very low voltages, even below 2.0V. XRD shows drastic changes at the initial low voltage charging, indicating irreversible crystal structural changes and question in the quality of the material. Extreme local HRTEM does not mean much. The reviewer pointed out that researchers can always pick a wanted feature from garden variety.

The reviewer did not agree with the interpretation of Cu XANES microscopy. The pristine material appears to contain some Cu^{3+} as indicated by the pre-edge peak, which requires confirmation by regular *in situ* XANES. The reviewer believed there are oxidation state changes in Cu. The low energy shift upon charging could be due to carbonate formation, CO_2 evolution, or oxygen evolution, leaving Cu^{2+} from pristine Cu^{3+}. It also shows phase changes or decomposition. The molybdenum-compound is not viable and may not be further pursued.

Reviewer 6:

The reviewer said that the project seems to be on track, but the goals are vague—make materials and evaluate—so the reviewer was not sure how one would assess progress. The metrics are not quantitative. The project would benefit from some focus.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer pronounced the collaboration with other organizations to be excellent. Collaborators include PNNL, BNL, SLAC, and LBNL.

Reviewer 2:

The reviewer said that the collaborations “looks good.”

Reviewer 3:
The reviewer commented that there are good ongoing collaborations with the other DOE laboratories (PNNL, BNL, and LNBL) and SSRL for material characterization and modeling.

Reviewer 4:
The reviewer said that there was good collaboration on characterization methods, but it would be good to have more collaboration with others working on the same fundamentals as it seems like there is overlap with other 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.

Reviewer 1:
The reviewer noted that future work is aimed at exploring new high-capacity cathode materials utilizing two lithiums, such as: $Li_2M_1M_2O_3$ and $Li_2M^IM^{II}$ O_3 where M^I and M^{II} are either Ni, Cu, molybdenum, manganese, or chromium. In addition, various Li-excess disordered compounds, such as $Li_{1+x}(Mn, Co, Ni)O_2$, $Li_{1+x}MoCrO_2$, $Li_{1.25}Nb_{0.5}Mn_{0.5}O_2$, and $Li_{1.2}Mn_{0.4}Ti_{0.4}O_2$, will be studied to increase oxidative stability and attain extra capacity, understand the role of disorder in increasing the Li diffusion pathways, and quantify oxygen participation in the redox process.

These studies are relevant to and address DOE goals.

Reviewer 2:
The reviewer suggested that the investigators first develop a rationale behind the proposed Li-excess disordered compounds and had many questions. The reviewer inquired about whether the delithiated structures of the proposed compounds are stable, and what the redox voltage will be so that what energy density should be expected. The reviewer did not understand why the investigators suggest looking into such compounds as $Li_{1.25}Nb_{0.5}Mn_{0.5}O_2$ and $Li_{1.2}Mn_{0.5}Ti_{0.5}O_2$. The reviewer asked whether they were selected based on sound theoretical consideration, and whether niobium and Ti are electrochemically active with a decent redox voltage.

Reviewer 3:
The reviewer asserted that it is not clear how the model is driving the synthetic approach of this investigation.

Reviewer 4:
The reviewer said that except for the molybdenum compounds, all are mundane and already extensively studied. As mentioned earlier, molybdenum compounds may not be viable due to poor performance and their cost.

Reviewer 5:
The reviewer's response was that there was a similar theme here and therefore comments similar to those previously made: if this is a make-evaluate-learn project, set some metrics about range of materials, variables, etc. Otherwise, establish a path toward improvement of the materials based on the learnings.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
For widespread use of EVs and PHEVs, the reviewer stated that it is imperative that LIBs be lightweight, compact, safe, and low-cost. The state-of-the-art materials are inadequate to fulfil these needs. High specific energy cathode materials are required to improve the specific energy for Li-ion cells and thus increase the

range for the vehicle and reduce overall cost for the battery. The state-of-the-art cathode materials are inadequate and provide capacities of only 170 mAh/g. New high-voltage and high-capacity cathodes, such as Ni-rich and Li-rich NMC formulations, are promising to meet the DOE goals, which this project has been addressing. Because oxygen loss or redox activity is an integral part of these cathodes, it is crucial to understand their effects on the structure of these cathodes.

Reviewer 2:

In the sense that the investigators are trying to develop high-energy cathode materials and to apply fine analytic tools, the reviewer would agree that this project is relevant to DOE objectives.

Reviewer 3:

The reviewer said, “Yes.” The reviewer further stated that the project is relevant because the aim is to develop better rechargeable batteries and reduce the nation's dependency on petroleum.

Reviewer 4:

The reviewer pointed out that fundamental understanding is key to the development of higher energy density batteries, which supports the overall objectives of the DOE program.

Reviewer 5:

The reviewed said resources are fine.

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 resources are adequate for the scope of the project.

Reviewer 2:

The reviewer asserted that the theoretical approach is simply copied from other sources and does not show a clear purpose.

Presentation Number: es164
Presentation Title: Thick Low-Cost, High-Power Lithium-Ion Electrodes via Aqueous Processing
Principal Investigator: Jianlin Li (Oak Ridge National Laboratory)

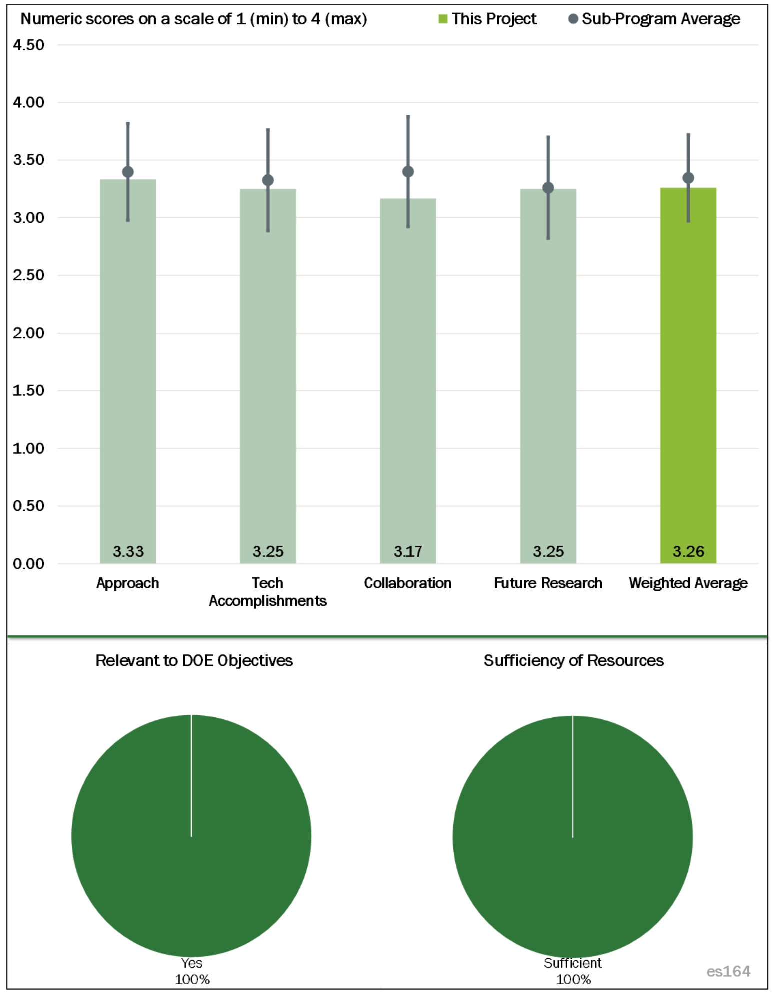

Figure 3-11 - Presentation Number: es164 Presentation Title: Thick Low-Cost, High-Power Lithium-Ion Electrodes via Aqueous Processing Principal Investigator: Jianlin Li (Oak Ridge National Laboratory)

Presenter

Jianlin Li, Oak Ridge National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer remarked that the approach is well defined to address the barriers, and it is integrated with the efforts from other teams. The objectives are also realistic and practical.

Reviewer 2:

The reviewer noted that the project is aimed at increasing energy density and decreasing costs by moving to aqueous-based, thick cathode electrodes. The project is using a high Ni-content cathode (NMC532). The project is well designed using industrially relevant materials, and the goals are feasible and aligned with efforts from other projects.

Reviewer 3:

The reviewer stated that the approach is good and works with reasonably sized cells made using equipment that is representative of what is used in manufacturing. The approach has identified barriers, especially retaining to performance at higher rates, and is addressing them.

Because this project is addressing electrode processing technologies (thick, water-based coatings), it is reasonable and appropriate to use commercially available, state-of-the-art materials, such as NMC532 in developing the new technologies.

Reviewer 4:

The reviewer commented that the approach is effective from the point of view of exchanging the n-methyl-pyrrolidone (NMP)-based slurry on the water-based or water-alcohol mixture. As a result, this reviewer explained, battery-pack, processing, and capital costs are reduced. However, using the proposed multiple coating for obtaining thick electrodes does not accomplish the task with maximum cost reduction.

Reviewer 5:
According to the reviewer, the project approaches the goals from multiple angles and addresses the cost and performance barriers. However, some of the directions may be straying from the goals. For example, it is not clear if the laser structuring of the electrode will not completely cancel the cost advantages and throughput of aqueous processing. An approach based on slurry formulation and coating conditions would be less inexpensive in mitigating the power and polarization issues.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer observed that the program appears to be progressing well and has successfully made thick NMC532 electrodes with aqueous-based mixed solvent system, with impressive results.

Reviewer 2:
The reviewer commented that the project has made good progress toward goals.

Reviewer 3:
The reviewer stated that several barriers and challenges, such as cracking and effective electrolyte wetting, have been identified, and the team is making progress in solving these problems.

Reviewer 4:
The reviewer mentioned that using the aqueous process for cathodes without compromising the performance of the cell seems to be a big challenge. The team has made significant progress toward avoiding cracking the cathode and improving the electrode integrity.

Reviewer 5:
The reviewer pointed out that currently, the electrochemical performance of water-based electrodes does not overcome or reach the performance of NMP-based electrodes. If water-based electrodes have the same C-rate capabilities, then their cyclability is less. And, for the opposite case, if cyclability is good, then the C-rate is not.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that the project has a substantial list of partners and collaborators across many different parts of the project.

Reviewer 2:
The reviewer commented that a broad group of partners is working on this project, the roles of several of the partners are specifically identified, and the future roles of industrial partners are mentioned.

There are no explicit details about how the partners actually interact or how often.

Reviewer 3:
The reviewer said that the team members have different capabilities and strengths. It looks there is not enough interactions among the collaborators.

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

Reviewer 1:
The reviewer remarked that the project has specific future work planned and milestones to determine future decision points and includes alternative development pathways to mitigate risk. It is well aligned with contributing to advancements in other DOE projects.

Reviewer 2:
The reviewer said that specific future work for next year and tentative work for the final year of this 4-year project have been identified.

Reviewer 3:
The reviewer commented that the microstructure of the electrolyte, including the porosity and tortuosity, might impact the battery performance significantly. The team should include that as one of the future directions as well.

Reviewer 4:
The reviewer pointed out that laser structuring for electrolyte transport inside electrodes will improve C-rate capabilities, but also will have a negative impact on energy density and cost of electrodes. The reviewer asked if it were possible to quantify these impacts.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer pointed out that this program is focused on decreasing costs and increasing energy density. Success in one or both of those areas may lead to accelerated EV adoption, which assists petroleum displacement.

Reviewer 2:
The reviewer answered yes and stated that the manufacturing process is a green and low-cost process, which might reduce the cost per watt-hour.

Reviewer 3:
The reviewer observed that the battery community has recognized that development of techniques to coat thick electrodes using water-based technologies offering the promise of improved energy density, improved specific energy, and reduced cost relative to current technologies using thinner coatings and NMP.

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

Reviewer 1:
The reviewer commented that the resources seem to be appropriate for this project. ORNL seems to have adequate facilities (dry room, etc.) and equipment (coaters, etc.). Collaborators offer access to other research, development, testing, and engineering (RDT&E) facilities.

At almost $4 million, the budget is significant. Without more detailed data, one cannot assess if the level of spending is cost effective relative to other organizations.

This project is scheduled to receive more than twice the funding allocated for the related project (ES207) on thick, low-cost electrodes produced with electron beam (EB) curing. ORNL is the lead on both projects; many of the same people are involved in both projects, so one assumes that the costs of labor and facilities are similar for the two projects. The presentations seem to indicate that the two projects are using some of the same facilities. The challenges facing the two projects are of similar magnitude—if anything, the EB project is more challenging.

If this Aqueous Processing project is appropriately funded, then the EB project is probably underfunded. Of course, if the EB project is properly funded, then this Aqueous Processing project may be overfunded.

Reviewer 2:
It is the reviewer's opinion that the researchers are doing substantial work and making progress considering the project's funding allotment. The reviewer asserted that the project team is a good example of what can be achieved its funds, and exclaimed that it is significantly more efficient than other projects.

Reviewer 3:
The reviewer stated that the team and collaborators have complementary strength and can accelerate the progress.

Presentation Number: es166
Presentation Title: Post-Test Analysis of Lithium-Ion Battery Materials
Principal Investigator: Ira Bloom (Argonne National Laboratory)

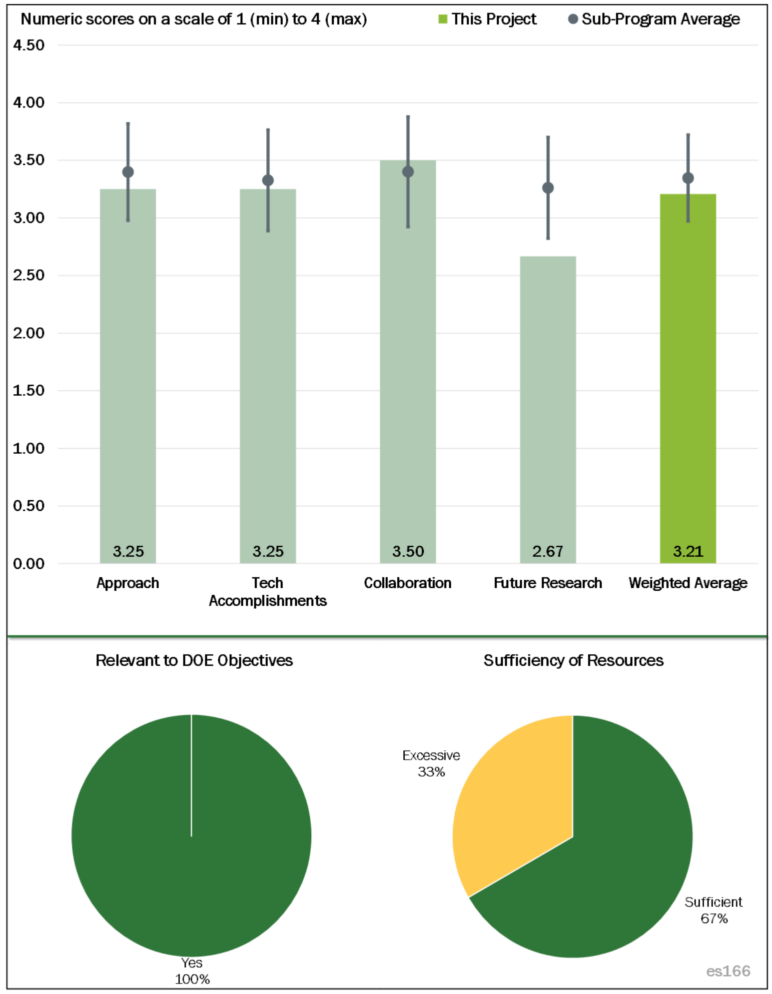

Figure 3-12 - Presentation Number: es166 Presentation Title: Post-Test Analysis of Lithium-Ion Battery Materials Principal Investigator: Ira Bloom (Argonne National Laboratory)

Presenter

Ira Bloom, Argonne National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer stated that the concerns, issues, and the goals were clearly defined. The method to evaluate the final product was also clearly identified.

Reviewer 2:

The reviewer said that the approach is good and is following standard methodology (test, dismantle, observe, and perform diagnostics).

Reviewer 3:

The reviewer noted that the investigative approach was determined during development of the project. Overall, experimental means used appear logical and have yielded the ability to conclude the behavior of a LIB package as it is subjected to intentional abuse.

Reviewer 4:

The reviewer commented that this is an effort to develop an understanding of how cells react to abuse using two different cathodes and two different binders. Another question was how processing affects abuse tolerance. The approach has been carefully laid out.

Reviewer 5:

The reviewer pronounced the approach of the post-test analysis to be good, and it addresses important issues related to abuse events. However, the reviewer believed the materials used should be more aggressive, especially the selection of a carboxymethyl cellulose (CMC)-graphite anode. This material is not advanced, and the approach is most likely repeating substantial work that has been covered by various other organizations. Emphasis on higher energy anodes and cathode pairs is advisable as well as alignment with new materials from CAMP or the Advanced Manufacturing Facility.

Reviewer 6:

The reviewer commented that only one type of abuse tests (i.e., overcharge) was performed. The work can be improved by leveraging Sandia National Laboratories (SNL) facilities and performing more types of abuse tests (e.g., thermal and mechanical abuse tests).

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer said that the PIs made good progress on comparing physical and chemical response of batteries with different types of binders under battery abuse conditions.

Reviewer 2:

The reviewer stated that good progress had been achieved by the ANL, ORNL, and SNL team this past year. ORNL made cells using two different binders and processes, SNL performed abuse testing, and ANL conducted post-mortem analysis.

Reviewer 3:

The reviewer stated that excellent progress was made toward program goals as they were outlined. The cell manufacturing, testing effort, and analysis work proceeded almost as scheduled.

Reviewer 4:

The team designed work and performed experimental efforts to meet established objectives for the fiscal year. However, some delays in outcome are reported. It remains for the team to establish a plan to address these delays.

Reviewer 5:

The reviewer observed that this project is in the very early stages so there are only a modest number of results. A number of diagnostics has been carried out on the two binders, and differences are observed, but it is too early to develop insights, in the opinion of the reviewer. A good question has been raised—what causes grain boundary corrosion—for future analysis. Transition metals were seen at the anode, which can be a useful diagnostic of abuse along with details of the morphology. Plating can be observed, but quantitative trends are hard to make out. One interesting result this reviewer noted is that binder failure seems to be important.

Reviewer 6:

The reviewer found that the project is making sufficient progress toward identifying binder-dependent physicochemical changes due to abuse conditions. A more rigorous statistical set of samples (replicates, large batch size) would help confirm the reproducibility and overall validity of the results.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer noted that while each national laboratory may have been able to do this complete program, the strengths of each national laboratory were used to their full advantage by collaborating to meet the program goals.

Reviewer 2:

The reviewer stated that the team reports considerable interaction between PIs at ORNL, SNL, and ANL as well with SMEs from other sectors.

Reviewer 3:
The reviewer called the collaboration arrangement excellent, with ORNL, ANL, and SNL each contributing their expertise.

Reviewer 4:
The collaboration is excellent as it includes three national laboratories (ANL, ORNL, and SNL).

Reviewer 5:
The reviewer said that all national laboratories are fully engaged in the research.

Reviewer 6:
The reviewer noted that ANL has partnered with ORNL to make the cells and SNL to abuse the cells. More collaboration to receive more types of cells and materials (cathodes, anodes, and electrolytes)—either through ORNL's part or other avenue—might accelerate the objective of understanding physical and chemical responses of battery materials under battery abuse conditions.

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.

Reviewer 1:
The reviewer remarked that the effort is projected to end in September 2018. The successful approach taken thus far will continue until completion.

Reviewer 2:
The reviewer commented that the slides include some indications of future research. The summary of future work is missing.

Reviewer 3:
The reviewer noted that there are no stated future plans other than what is stated in the objectives. Ideally, a “Future Plans” slide that included details on the points in the objectives would have been excellent.

Reviewer 4:
The reviewer commented that the poster presents a rather generic “milestone chart.” Further detail would have been useful. A slide depicting future work was not found within the poster slide deck.

Reviewer 5:
The reviewer stated that no future research slides were provided although this project continues until September 30, 2018 (only 50% complete). This appears to be an unfortunate oversight on behalf of the PI. Additionally, the proposed future work from the 2016 presentation was not addressed in this 2017 presentation.

Reviewer 6:
The plan is to look at Li-iron-phosphate (LFP) composition next year with different combinations of binder. It was not clear to the reviewer whether the plans will yield new insights, especially at a fundamental level.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer mentioned that understanding the potential negative response to real world abuse scenarios for this technology and identifying ways to significantly reduce that response are critical to public acceptance of this technology. This project fully supports that need.

Reviewer 2:
The reviewer asserted that the introduction of LIBs into the transportation sector will result in lightweighting of designed vehicles, which serves to conserve energy, whether it be petroleum or other energy source. However, this project is one that is focused on energy storage, regardless of generating source.

Reviewer 3:
The reviewer viewed battery safety as critical for widespread adoption of EVs and the displacement of petroleum. Projects such as this serve as a tool to determine overall safety and post-cycling analysis.

Reviewer 4:
The reviewer stated that an effective post-analysis procedure is important for battery development and will help accelerate the EV adoption.

Reviewer 5:
The reviewer remarked that the project supports DOE objectives. It is important to perform failure analysis on batteries so that we can move forward in the development of an affordable battery that can meet DOE goals.

Reviewer 6:
It seems useful, but it was unclear to the reviewer how knowing the various responses to abuse will help make safer batteries. The reviewer further noted that the project team will test different additives, but again, was unsure how looking at morphology changes will add knowledge.

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

Reviewer 1:
The reviewer stated that the funding needed to have these three national laboratories provide their expertise to a project is sufficient.

Reviewer 2:
Based on the results obtained this past year, the reviewer remarked that it appears the investigators have sufficient resources to successfully complete the project.

Reviewer 3:
The reviewer noted that the collaborative laboratory team has access to a wide variety of tools and resources to support conduct of this effort.

Reviewer 4:
The reviewer said resources are okay.

Reviewer 5:
Based upon the presentation, a small set of cells were produced for testing (fewer than 30 cells), abuse, and subsequent characterization. The reviewer would like to have seen additional anode or cathode chemistries or a larger representative set of cells with the time and resources available to them. This would help solve their stated objective of elucidating physical and chemical response of battery materials under battery abuse conditions.

Reviewer 6:
It seems to the reviewer that most analysis presented so far (especially just overcharge abuse test) can be done in coin cell instead of pouch cell.

Presentation Number: es167
Presentation Title: Process Development and Scale-Up of Advanced Active Battery Materials—Gradient Cathode Materials
Principal Investigator: Greg Krumdick (Argonne National Laboratory)

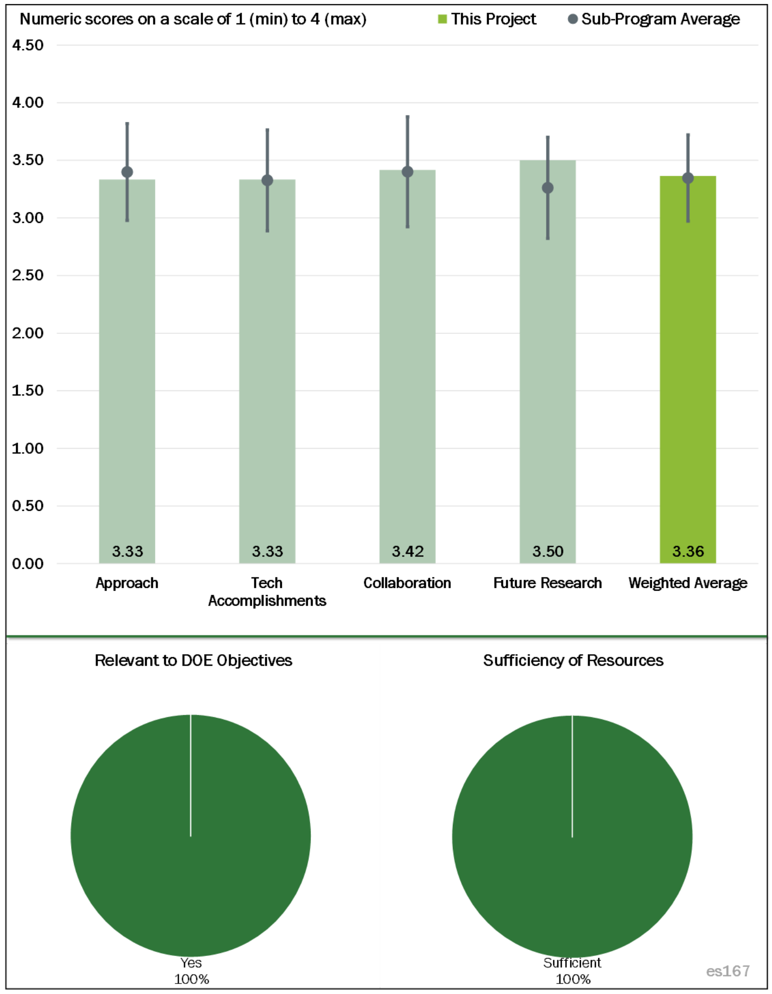

Figure 3-13 - Presentation Number: es167 Presentation Title: Process Development and Scale-Up of Advanced Active Battery Materials—Gradient Cathode Materials Principal Investigator: Greg Krumdick (Argonne National Laboratory)

Presenter
Youngho Shin, Argonne National Laboratory

Reviewer Sample Size
A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that the approach is excellent and is the type of study needed if DOE is to improve batteries for electric drive vehicles. The effort undertaken is a conduit among identifying advanced battery materials in the laboratory, market evaluation of the materials, and high volume manufacturing.

Reviewer 2:
The reviewer stated that the objective of the project is to perform systematic studies in order to define the optimum concentration of gradient cathode materials and to develop processes for the scale-up of these high energy cathode materials. The project has a sound approach in evaluating various types of gradient cathode particles and in developing synthesis processes for the production of large quantities of materials.

Reviewer 3:
The reviewer remarked that the approach to making gradient materials is sound and based on scalable technologies, allowing the work to potentially make a large impact on the field.

Reviewer 4:
The reviewer commented that the project is carefully planned and technical barriers are addressed.

Reviewer 5:
The reviewer found the approach to be reasonable to scale up the materials and to reduce cost by transitioning from batch process to continuous synthesis process.

The core-shell and core gradient approaches have been studied for the last few years to mitigate stability issues while achieving high energy density cathodes. There is still no convincing full cell data on the benefit of the core gradient or core shell materials. Because the surface is porous, it remains unclear why the electrolyte will not diffuse into the interior and react with the less stable core material. They should provide some quantifiable energy density gains (Wh/l and Wh/kg) at the full cell level.

Reviewer 6:

The reviewer asked that the target material be defined: gradient cathode material with greater than 220 mAh/g with greater than 95% capacity retention at 100 cycles. The best gradient cathode material does not reach 220 mAh in the voltage range tested. The reviewer would like to have seen the voltage range extended to achieve greater than220 mAh/g, at least within the first five cycles. The reviewer would also like to have seen at least three cells tested for each lot to achieve some reasonable statistics, especially for the scaled-up lots where there should be plenty of sample for coin cell tests.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer noted that excellent progress was achieved this past year (622 gradient material characterization, 811 gradient material synthesis, and comparison of 811 gradient material with commercial NMC333 at various temperatures).

Reviewer 2:

The reviewer stated that the gradient NMC material seems to offer a real technical breakthrough. The reviewer asked how the gradient material described in this work is different than existing commercial gradient material offered by TIAX.

Reviewer 3:

The reviewer remarked that progress is excellent, but suggested that more consideration of crystal homogeneity in the materials produced needs to be demonstrated.

Reviewer 4:

The reviewer said that various types of gradient materials are synthesized, and their electrochemical performances are compared. Microscopy and spectroscopy techniques are used to characterize the synthesized particles. The findings of the project show that the synthesized core-gradient and core-shell compounds exhibit better performance (capacity retention and rate capability) compared to the available commercial NMC cathode materials. Thus, gradient compounds are promising to improve the performance of LIBs; however, as mentioned by the team, their commercialization needs further improvement of manufacturing methods. The project needs to place more emphasis on the scale-up of concentration gradient oxides.

Reviewer 5:

The reviewer observed that there was good use of analytical tools, such as EDS and XAS, to characterize and validate the concentration gradient or compositions in the gradient or core-shell materials.

They showed better rate capability and limited cycling performance in half cells using their 811 core gradient material. However, they ultimately need to validate the performance advantage of the 811 core gradient material in a full cell.

Reviewer 6:

The reviewer commented that progress toward actually making a core gradient material that cycles well is good, but it is not clear what the fading mechanism is. The C/10 results are almost identical for the core shell and core gradient materials and almost meet the cycle test even at 55°C, but there is a divergence between the two at C/2 cycling. It is important to do some diagnostic tests, such as impedance measurements to seek the reasons for this difference. It would be good to be certain that there are no porosity differences between the two types of cathodes.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer asserted that there are excellent collaborations on this project.

Reviewer 2:
The collaboration that exists is excellent. It includes academia (University of Illinois and Technical University Braunschweig), national laboratories (BNL and ANL), and industry (Laminar).

Reviewer 3:
The reviewer commented that the project team has various collaborations with DOE national laboratories, universities, institutions, and companies.

Reviewer 4:
The reviewer stated that there was good collaboration, and the roles of each collaborator were specified.

Reviewer 5:
The reviewer observed that collaboration seems good by virtue of the Materials Engineering Research Facility (MERF) at ANL.

Reviewer 6:
The reviewer observed that there was a good list of collaborators, but noted that adding other industrial collaborations may further strengthen this project. The reviewer noted that adding other industrial collaborators may further strengthen this project.

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

Reviewer 1:
The reviewer said that the proposed future work is well thought out and logical. It includes investigation of the promising 811 cathode material. A Taylor Vortex Reactor continual process is being developed that will result in higher quality, more affordable material.

Reviewer 2:
The reviewer particularly liked the plans for the vortex reactor and described this as cutting edge.

Reviewer 3:
The reviewer noted that development of continuous synthesis process is one of the critical aspects of future work.

Reviewer 4:
The reviewer commented that future research is well planned and is in line with the objectives of the project.

Reviewer 5:
The reviewer wanted to see more effort devoted to demonstrating performance in full cells in order to validate the benefits of core-shell or gradient materials.

Reviewer 6:
The reviewer would like to have seen an expanded voltage range to achieve the 220 mAh/g target added to the future research proposal.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
Because the project aims to scale up the production of layered Li transition-metal oxides that exhibit high energy storage, low-cost, non-toxicity, and abundant elements, the reviewer remarked that it thus facilitates the transition from a fossil fuel based economy to one that may be driven by a mixture of fuels.

Reviewer 2:
The reviewer observed that this project is highly relevant to DOE objectives. New advanced cathode materials are generally synthesized on the gram scale without quality control and reproducibility. These materials need to be tested and validated in large format prototype cells before going to high-volume manufacturing. This project allows synthesis of sufficient material for in-depth characterizations that eventually allows transition to the car manufacturer.

Reviewer 3:
The reviewer pointed out that high-capacity cathode materials are crucial to the success of DOE programs.

Reviewer 4:
The reviewer opined that this work improves U.S. technological ability to improve manufacturing of electrode materials for vehicle electrification.

Reviewer 5:
The reviewer said that a stable, high-capacity cathode is relevant to DOE's objectives.

Reviewer 6:
The reviewer stated that this project meets DOE objectives.

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

Reviewer 1:
The reviewer commented that the project team has access to sufficient resources and collaborations in order to perform the proposed tasks.

Reviewer 2:
The reviewer noted remarked that $1.7 million should be sufficient for the proposed effort.

Reviewer 3:
The reviewer stated that there are sufficient resources to accomplish the proposed milestones.

Reviewer 4:
The reviewer said that the resources seem appropriate.

Presentation Number: es168
Presentation Title: Process Development and Scale-Up of Critical Battery Materials—Continuous Flow Produced Materials
Principal Investigator: Greg Krumdick (Argonne National Laboratory)

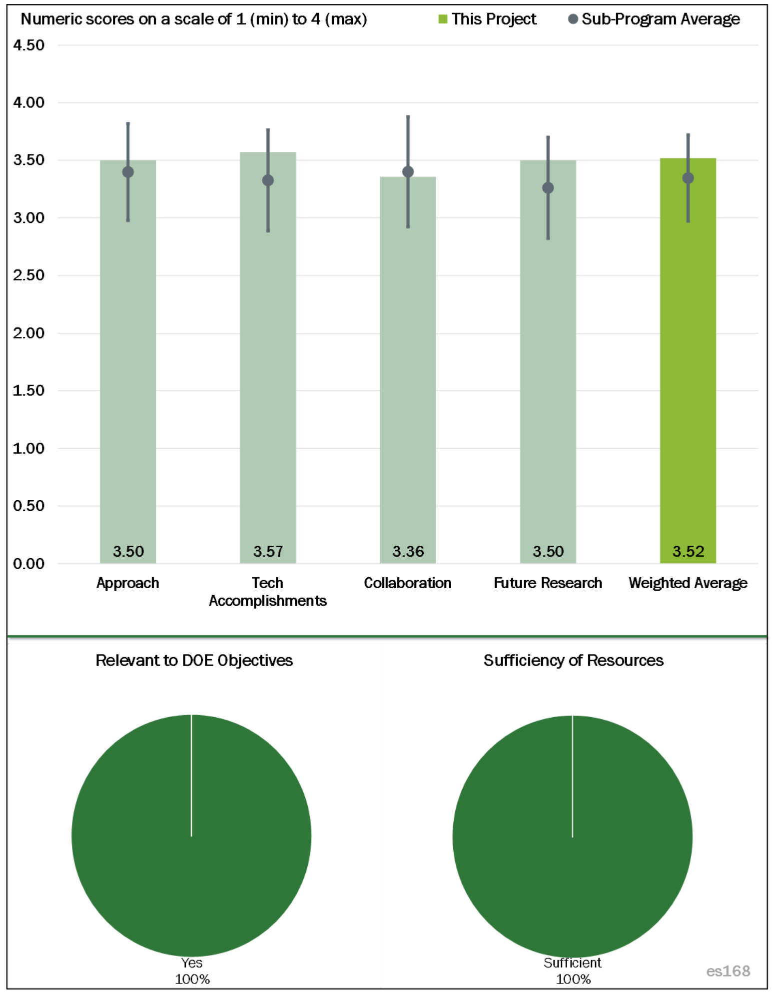

Figure 3-14 - Presentation Number: es168 Presentation Title: Process Development and Scale-Up of Critical Battery Materials—Continuous Flow Produced Materials Principal Investigator: Greg Krumdick (Argonne National Laboratory)

Presenter
Krzysztof Pupek, Argonne National Laboratory

Reviewer Sample Size
A total of seven reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
In so far as the goals of this program include evaluating manufacturing technologies, developing cost effective processes, producing sufficient materials quantities for evaluation, and determining effect of purity profiles on battery performance, the reviewer observed that this group has made great progress. Materials have been distributed to several partner research groups for evaluation, and the new flow reactor setup provides a means of scale-up with advantages over non-flowing reactors, including improved mass and heat transfer kinetics. This continuous system has been used to synthesize several electrolytes that have been demonstrated as useful additives in LIBs. Analysis of a trimethylsilyl-functionalized carbonate shows that this scalable additive may be useful as an LIB solvent. Catalysts for effective reactions were identified in batch versus flow conditions, resulting in the identification of alumina as a low-cost catalyst.

Reviewer 2:
The reviewer reiterated that the goal of the project is to develop cost-effective processes for the manufacturer of large quantities of organic solvents for LIBs. Continuous flow reactors for production of organic solvents have been successfully tested, the basic properties of the products are evaluated, various catalysts are examined, and the process has been optimized. The new materials synthesized using flow reactors seem to be promising as future solvents and could enable safer liquid-based electrolytes for LIBs. The project team is planning to perform additional experiments to confirm the safety of the solvents.

Reviewer 3:
The reviewer acknowledged that this is very relevant work for materials development, and the approach is relatively unique in being agnostic to the source and targets of the proposed materials.

Reviewer 4:
This reviewer liked the stated concept of trying to develop new processes that will take some risk away from industry and also provide small quantities of new materials for testing

Reviewer 5:
The reviewer commented that the work was interesting.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
By providing large quantities of materials with consistent quality, the reviewer pointed out that this program meets a critical need by linking the discovery of advanced battery materials with market volume and high volume manufacturing. The consequence of these accomplishments includes industrial validation of materials in large format cells, which may lead to further advances in research projects involving new materials inspired by results of cycling data obtained from the same batch of materials.

Reviewer 2:
The reviewer said that the development of a cost-effective process for the synthesis of organic solvents, screening the effect of various catalysts, and evaluation of several new solvents for LIBs is the main accomplishments of the project. The outcome of the project at this point is toward the development and scale-up of novel manufacturing processes for battery materials.

Reviewer 3:
The reviewer mentioned that developing a process for the methyl ((trimethylsilyl)methyl) carbonate MTMSMC solvent seems like a good choice to test concepts of this program. The team has made excellent progress.

Reviewer 4:
The reviewer noted that many materials were scaled up, especially in the field of electrolyte solvents.

Reviewer 5:
The reviewer said that good progress has been made.

Reviewer 6:
The reviewer had a question about not fully understanding the role of alumina catalyst.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that the project team has various collaborations with DOE national laboratories, Army laboratories, and leading companies. The collaborations are at both scale-up and materials evaluation levels.

Reviewer 2:
The reviewer noted that there is appropriate collaboration with other institutions.

Reviewer 3:
The reviewer mentioned that several partners are identified (ORNL, ANL research groups, and Dellatech), and more are identified as providing support (ARL, LBNL, PNNL, SolidEnergy Systems, and Toyota Technical Center).

The nature of collaborations and support is not well identified on the slides provided. After forgetting to ask about collaborations at the poster session, the reviewer wanted the participants to be more specific about the nature of their collaborations and supportive interactions.

Reviewer 4:
The reviewer remarked that many partners are listed; however, it is not clear how each one is participating in the project.

Reviewer 5:
This reviewer commented that adding industrial collaborators would strengthen this project.

Reviewer 6:
The reviewer did not see evidence of strong collaborations on the production and distribution of MTMSMC and inquired if there is a ready market for this product.

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.

Reviewer 1:
The reviewer noted that remaining challenges and barriers are discussed, and future activities are well detailed and are sound. In particular, the proposed plan to investigate the effect of chemical purity on electrochemical performance carries significant benefits for optimum manufacturing of materials.

Reviewer 2:
The reviewer said that good future work was proposed.

Reviewer 3:
The reviewer asserted that targeting approximately five new materials for process R&D, investigating purity versus electrochemical performance, and evaluating new technology platform are reasonable. Perhaps more detail could be provided on how materials are selected for scale-up and evaluation.

Reviewer 4:
The reviewer commented that the list of new materials and research directions seems to be too long for the remaining time of the project.

Reviewer 5:
The reviewer stated that the current project is essentially complete and would like to have seen more specifics in planning what is next.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer pointed out that decreasing LIB cost and improving performance allow for the increased incorporation of fluctuating renewable energy resources onto the electrical grid.

Reviewer 2:
The reviewer stated that the project will significantly impact the manufacturing of critical materials for energy storage and thus facilitates the transition from a fossil fuel based economy to one that may be driven by a mixture of fuels.

Reviewer 3:
The reviewer noted that this work improves U.S. technological ability to improve manufacturing of electrode materials for vehicle electrification.

Reviewer 4:
The reviewer said yes, because of the battery for EVs.

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

Reviewer 1:
The reviewer stated that the project team has access to sufficient resources and collaborations in order to perform the proposed tasks and is expanding its collaborations and scale-up efforts.

Reviewer 2:
The reviewer said that the resources appear to be adequate.

Reviewer 3:
The reviewer observed that the resources are sufficient.

Reviewer 4:
The reviewer found the resources to be sufficient for the project to achieve.

Reviewer 5:
The reviewer commented that resources seem sufficient based on previous year spending. However, time may be too short for all remaining tasks.

Presentation Number: es183
Presentation Title: *In Situ* Solvothermal Synthesis of Novel High-Capacity Cathodes
Principal Investigator: Feng Wang (Brookhaven National Laboratory)

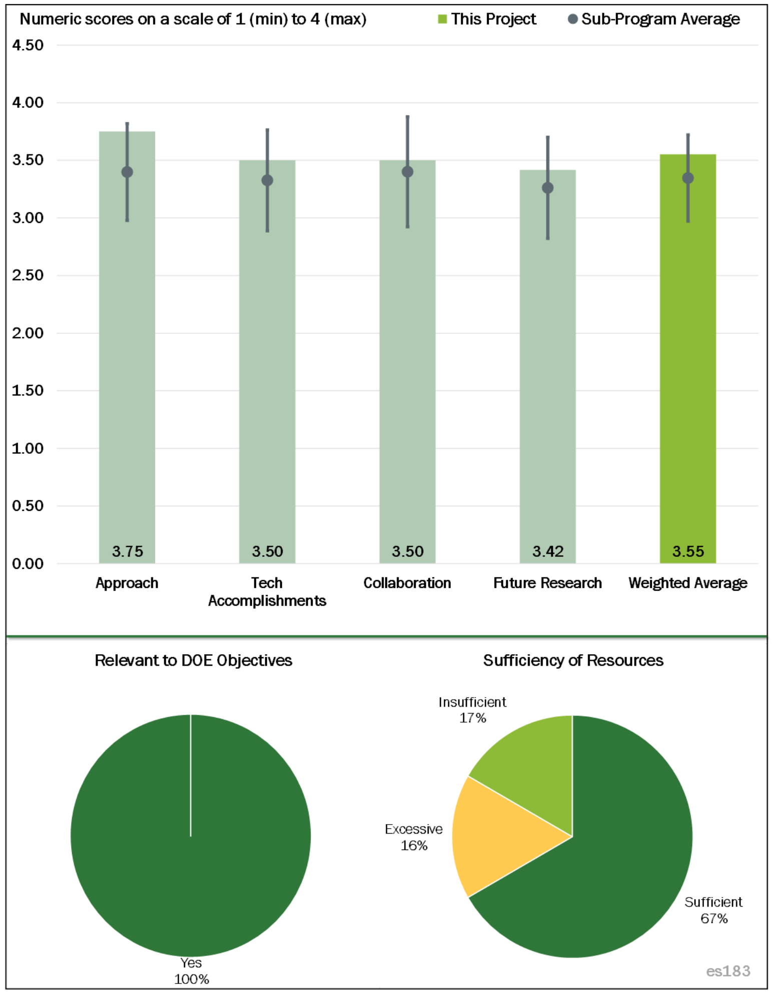

Figure 3-15 - Presentation Number: es183 Presentation Title: *In Situ* Solvothermal Synthesis of Novel High-Capacity Cathodes Principal Investigator: Feng Wang (Brookhaven National Laboratory)

Presenter

Feng Wang, Brookhaven National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer observed that studying the synthetic conditions by *in situ* methods is an outstanding approach, guiding toward the optimal condition for highly tuned materials.

Reviewer 2:

The reviewer summarized the objective of this project, which is to develop low-cost cathode materials with an energy density of greater than660 Wh/kg and electrochemical properties (cycle life, power density, and safety) consistent with USABC goals.

Designing and synthesizing specific cathode materials have proven difficult due to the complexity of the reactions involved in chemical synthesis and high sensitivity of the phases, stoichiometry, and morphology to the synthesis conditions (such as pH value, Li content, sintering temperature and atmosphere, and heating and cooling rates). The effort in the current year has focused on developing Ni-rich layered oxides ($LiNi_{1-x}M_xO_2$ where M=Co, Mn, etc.) through synthetic control of the phase, stoichiometry, and morphology, all of which determine the cathode performance.

To control these key parameters, new tools and techniques are being developed for *in situ*, real time studies of synthesis reactions, for example, using *in situ* solvo-thermal synthesis for LFP cathodes. For the Ni-rich cathodes, a similar *in situ* technique being developed here would enable the tuning of the structure and property with Co and Mn substitution; it would also track phases and cation ordering in the intermediates and thereby quantify thermodynamic and kinetic parameters governing the synthesis process.

Because the high-capacity cathode undergoes considerable structural changes in the bulk, with cation disorder and phase transformations, an *in situ* study is an excellent tool to track these changes and formulate reaction mechanisms. The approach here addresses the technical barrier of understanding the structural changes in the high-capacity cathode in Li-ion cells.

The project is well designed, feasible, and well integrated with other effort.

Reviewer 3:

The reviewer said that this project starts high-energy, low-cost, and stable NMC cathode materials from monitoring at the molecular level to establish the synthesis-structure-properties relationship. The smart system of *in situ* synthesis has proven to be a power technique in identifying the key parameters affecting the structure and properties of the products obtained. The change from precursors to the end products has been quantitatively documented for people to alter the experimental conditions to obtain what one desires. The reviewer said that this is remarkable.

Reviewer 4:

The reviewer observed that we spend a lot of time and resources understanding how materials work or fail in a battery. We characterize materials in an attempt to understand how they work. But, cathode materials made via different processes perform differently—and this is a much less studied field. If we want to make the best performing, lowest cost materials, this type of work is critical and should be increased.

The reviewer stated that it would be great to extend this to other synthesis methods—even if they had to be *ex situ* with sampling of materials as a function of time. It needs to include commercially relevant processes.

Reviewer 5:

The reviewer commented that a thorough understanding of the synthetic mechanism and high temperature thermo-chemical aspects are greatly needed for successful development of high-energy cathode material. This project aims to develop tools and techniques to identify the reaction pathways to obtain materials with desired phases and properties.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

All milestones have been completed with some excellent results. Quantitative measurement of the chemical composition as well as the structure of the materials obtained are superbly demonstrated. The temperature effect has been convincingly shown from the synthesis process as well as the product performance.

Reviewer 2:

The reviewer called out good progress toward goals and was glad that the team added another synthesis capability. The calcination studies are also important and interesting, and the team has done a lot of work here.

Reviewer 3:

The reviewer gained great insights concerning the local and long range structures of transition metals in NMC family materials but would like to have seen some correlations between these synthetic variations and stability over cycles and more detail about the capacities.

Reviewer 4:

The reviewer asserted that good progress had been made in developing *in situ* techniques during the synthesis of cathode materials, which enable us to identify reaction pathways and intermediates and to quantify thermodynamic and kinetic parameters governing the synthesis process.

This process was utilized earlier for LFP cathodes, and this year methods were developed for making a series of Ni-rich layered oxides. Specifically, *in situ* reactors specialized for solid-state synthesis under controlled atmosphere and new synchrotron-, neutron-based *in situ* probing techniques were developed. The techniques were then applied to identify the phases being formed in the layered and spinel composites in Ni- and Co-rich systems with tuned electrochemical properties.

Similarly, structural evolution details, such as phase transformation, layer ordering, Li-Ni mixing, slab distance, etc., were identified as a function of temperature during synthesis of Ni-rich oxide ($LiNi_{0.8}Co_{0.2}O_2$) and determined optimal conditions for synthesizing $LiNi_{0.8}Co_{0.2}O_2$ with low cationic disordering.

Later, this method was used to determine the dependence of the reaction pathway on precursors in the synthesis of Ni-rich layered oxides with different precursors and different temperatures (850ºC has been identified with fast ordering kinetics and yields material of high electrochemical activity).

Finally, NMC71515 was synthesized with low cationic disordering and high reversible capacity through synthetic control of the kinetic reaction pathway. Though there is good understanding of the materials synthesized here, the performance is not particularly impressive, the capacities are low, and the cycle life is moderate with these materials. Nevertheless, this synthetic approach with *in situ* characterization is an excellent tool to develop new materials with known properties.

Overall, the progress is quite good and well directed toward the DOE goals.

Reviewer 5:
This project successfully developed *in situ* probing techniques to understand factors that affect resulting crystallographic structure of cathode materials, which could help precisely correlate structural-electrochemical properties of synthesized cathode materials. Instead of synthesizing a bunch of compositions and simply testing them, the reviewer expected this kind of study from national laboratories to have given a fundamental understanding of targeted cathode materials.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed a great job and congratulated the team for having many collaborators. This reviewer also praised the team as using the unique capability of BNL to work very effectively with a wide variety of partners, and encouraged the team to keep it up.

Reviewer 2:
The reviewer pronounced the coordination to be good.

Reviewer 3:
The reviewer acknowledged that there are good ongoing collaborations with the other DOE laboratories (ORNL, LBNL, and ANL) and with the universities.

Reviewer 4:
The reviewer commented that collaborations with other national laboratories are important for materials characterization. The collaboration with three universities leads to the good selection of synthesis conditions to start with. Some of the collaborators have extensive industrial experience with large scale materials production as well as battery manufacturing.

Reviewer 5:
The reviewer said that collaborations are clearly demonstrated and organized.

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.

Reviewer 1:

The reviewer stated that the PI knows what he is doing. In addition to having even more powerful *in situ* monitoring of the reaction process, the PI also proposed to test other high-energy, low-cost, and stable materials. The reviewer opined that this is quite logical and explained that the team can also achieve the planned research with research that others can only envy.

Reviewer 2:

The reviewer remarked that future studies will continue to provide an understanding of the synthetic process of high capacity cathode materials through *in situ* solvo-thermal synthesis. Specific plans are to continue to work on *in situ* probing and synthetic control of the structural ordering in NMC cathodes by focusing on Co and Mn effects on the structural ordering, cooling effects on the cationic ordering and electrochemical properties, local oxidation process of Ni versus Mn-Co within single particles, and morphology control through tuning synthesis conditions. Later, these methods and the optimized set of experimental conditions will be extended to the Li-rich LL and LLS composite oxides.

These studies are quite relevant to bringing the project to a closure and addressing the DOE goals.

Reviewer 3:

According to the reviewer, future work is well stated. The reviewer highly recommended that efforts continue to advance this year's work and develop new *in situ* techniques for thorough mapping of synthetic parameters and resulting structure and electrochemical properties. Close collaboration with other BMR projects on materials development should be done.

Reviewer 4:

The reviewer suggested that the project expand its capabilities in order to learn more.

Reviewer 5:

As mentioned earlier, the reviewer recommended gaining strong correlation among synthetic condition, structural information, capacity, and stability.

Reviewer 6:

The reviewer commented that it will also be important to study the effect of Mn in the high Ni NMC materials and compare that to the NCA materials with the similar Ni content.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

For widespread use of EVs and PHEVs, the reviewer stated that it is imperative that the LIBs be lightweight, compact, safe, and low-cost. The state-of-the-art materials are inadequate to fulfil these needs. High specific energy cathodes with low-cost are required to improve the specific energy for Li-ion cells and thus increase the range for the vehicle and reduce overall cost for the battery. Nickel-rich and Li-rich NMC cathodes are promising to provide the required high energy densities, but these materials are difficult to synthesize because structural properties and a good fundamental understanding of the structural aspects, phases changes, and cation ordering are unknown, which this project has been addressing. This project is expected to result in cathode materials that will make LIBs more acceptable for EVs and PHEVs, which in turn reduces petroleum dependence.

Reviewer 2:

The reviewer commented that this project not only gives novel products for high-energy, low-cost, and stable cathode materials of LIBs, it also provides a powerful tool for people to optimize the synthesis conditions for other materials. The synthesis-structure-properties relationship can be quantitatively monitored with the variation of experimental conditions. Thus, it will also help many researchers in the field to obtain their desired products within a shorter period of time. The materials, if used in battery applications, can definitely benefit the renewable energy storage or power supply for EVs. Both applications would displace petroleum.

Reviewer 3:

Ultimately, according to the reviewer, processes to make lower cost or more consistent materials will support the overall DOE objectives. This project has a good balance of fundamental understanding and practical application.

Reviewer 4:

The reviewer said yes.

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

Reviewer 1:

The reviewer observed that all milestones have been completed with outstanding results. An excessive amount of useful data has been obtained. The reviewer commented that the synthesis-structure-properties relationship has been established for a couple of materials, and noted that the approach can be applied to many other materials. Additionally, this reviewer described the developed tool as very powerful.

Reviewer 2:

The resources are adequate for the scope of the project.

Reviewer 3:

The reviewer said yes.

Reviewer 4:

The reviewer noted that the practical limitations on beam time may impede this project.

Presentation Number: es201
Presentation Title: Electrochemical Performance Testing
Principal Investigator: Ira Bloom (Argonne National Laboratory)

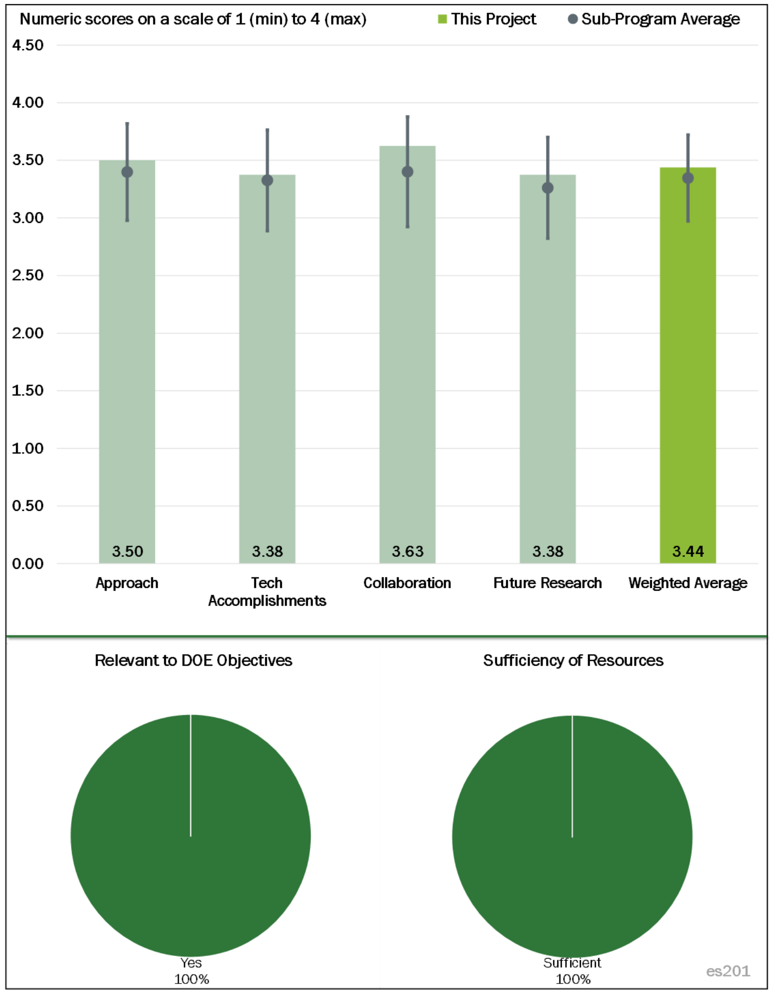

Figure 3-16 – Presentation Number: es201 Presentation Title: Electrochemical Performance Testing Principal Investigator: Ira Bloom (Argonne National Laboratory)

Presenter
Ira Bloom, Argonne National Laboratory

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
According to the reviewer, the use of very public methods to provide a highly competent and independent evaluation of cells of many sizes is just what is needed.

Reviewer 2:
The reviewer said that the project is well designed and integrated with other efforts, particularly as a validation for USABC projects. The reviewer understood the desire for testing support results to be maintained as confidential information; however, this does make it difficult to truly see how and whether barriers are being addressed by cells delivered by the USABC programs.

The publicly available results on fast charging are indeed interesting and promising. It would be useful in the future to show what percentage of the budget is spent on projects that result in data that cannot be shared publicly and on the decision process for how the budget is appropriated for testing and results that can and are shared publicly.

The comparison to activities in China is very interesting, and the presenters' stated desires to test more relevant chemistries were encouraging. It may be useful in these cross-geography studies to test batteries produced in China with the developed protocols. As EVs become more prevalent on U.S. roads and infrastructure (with presumably an increasing number of cells and packs produced outside the United States), it may be useful to fully characterize imported automotive batteries on an ongoing basis alongside emerging USABC program batteries.

Reviewer 3:
The reviewer remarked that the fast charging development for an EV battery is important. The time to fast charge is assumed to be equivalent to internal combustion engine (ICE) fueling.

Reviewer 4:
The reviewer commented that the project is well designed, but not very feasible, so far. This reviewer further opined that this kind of battery test or characterization work depends on how to secure the various batteries on time. Otherwise, it would change all technical approaches. The reviewer also indicated that no clear or solid information is shared about how to approach performing the work.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer pointed out that the technical accomplishments toward the DOE goals are excellent, and it is clear that the sustained investment in high quality facilities and experienced personnel is required to continue ongoing success of this project.

Reviewer 2:
While the poster focuses on the new China work, the reviewer stated that the Chinese continue to do a great deal of independent evaluation. Both are quite valuable. China is a major market and having a reliable testing agency there giving results similar to U.S.-based testing is of value to industry.

Reviewer 3:
The reviewer stated that the issues of fast charging are addressed thoroughly.

Reviewer 4:
The reviewer opined that because many similar studies have been reported, the technical accomplishment is very minimal.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer responded, yes. Many different cell suppliers along with various chemistries are an outstanding outcome of this project.

Reviewer 2:
The reviewer found the collaboration with USABC, China, and other DOE projects and national laboratories to be excellent. It would be interesting to have seen more about the process for coordinating with confidential programs after data are generated. As an example, this reviewered asked whether only data are transmitted back to the parties or whether conclusions, recommendations, and follow-on testing are also part of the process. It would be interesting to evaluate how a more robust, fee-for-service approach could be cultivated. The reviewer believed this exists, but it is unclear how frequently this is utilized. Such a service could enable smaller companies and venture-backed startups working on emerging technologies to also participate and utilize laboratory resources outside the direct pathway of receiving a major DOE project.

Reviewer 3:
The reviewer acknowledged that the work with China is more than might be expected given their core mission.

Reviewer 4:
The reviewer commented that the meeting with vehicle developers, battery developers, charger developers, and others was held successfully.

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.

Reviewer 1:
The reviewer noted that the project is doing what is needed; there is no real change expected or desired in the work they do.

Reviewer 2:
The reviewer found the future research plan to be compelling. The only thing that could be interesting is to better document the future research options that were not pursued and why this was the case.

Reviewer 3:
The reviewer said that the variables for fast charging are addressed. However, the resultant energy density and specific energy also should be reported.

Reviewer 4:
The reviewer stated that the future plan must be more organized in regard to the project's final objectives.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said yes. All this work is very relevant to the DOE overall goal to reduce petroleum usage and reduce all environmental issues.

Reviewer 2:
The reviewer noted that the work is highly relevant. Without independent verification, progress to the marketplace would be much slower.

Reviewer 3:
The reviewer observed that the fast charging aspects of this program are intended to overcome not just technical barriers, but psychological barriers as well (e.g., "refueling" time and habits with respect to conventional systems).

Reviewer 4:
The reviewer responded affirmatively and suggested that faster recharging will make deeper penetration in vehicle market acceptance.

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 appear to be sufficient.

Reviewer 2:
The reviewer noted that all resources are very sufficient except for industrial support for the program.

Reviewer 3:
The reviewer opined that the researchers seem to be able to do the job with the funds, but there would be value in more capital and accompanying annual funds to buy more cyclers and man them so more cells could be handled.

Reviewer 4:

The reviewer noted that the design of cells and battery pack development will be done at USABC.

Presentation Number: es202
Presentation Title: INL Electrochemical Performance Testing
Principal Investigator: Matt Shirk (Idaho National Laboratory)

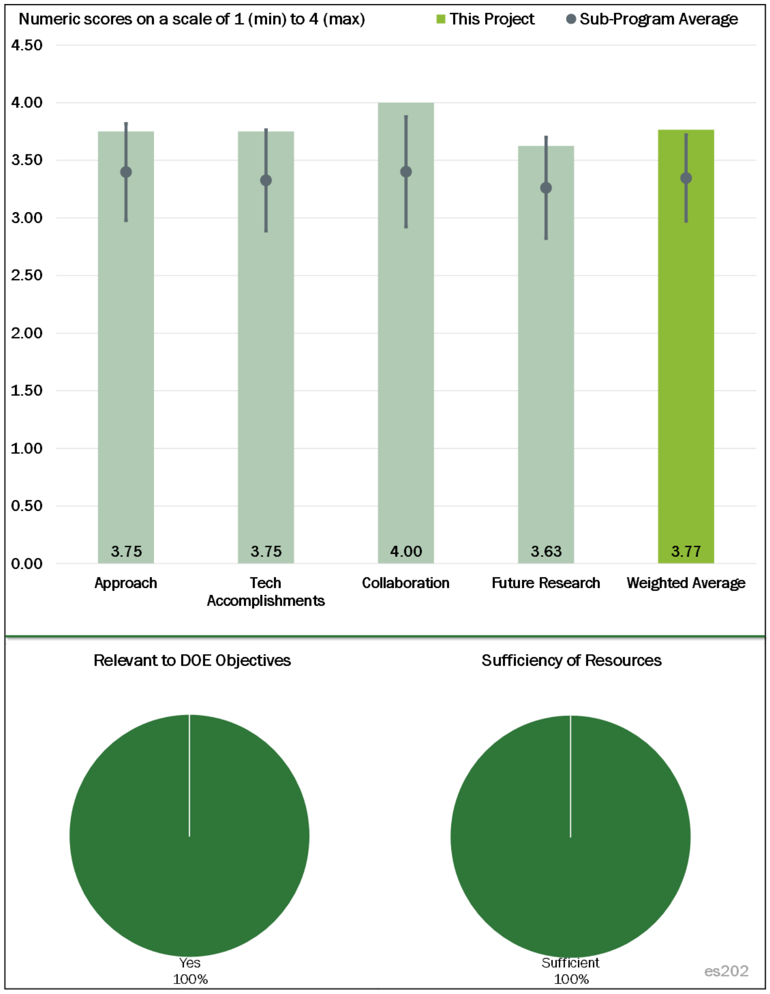

Figure 3-17 – Presentation Number: es202 Presentation Title: INL Electrochemical Performance Testing Principal Investigator: Matt Shirk (Idaho National Laboratory)

Presenter

Matt Shirk, Idaho National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer found the performance testing at many different batteries levels to be very significant for the future of batteries.

All these technical approaches are very feasible and integrated into other projects easily.

Reviewer 2:

The reviewer called out the work as not only a first class independent evaluation of any type of cell but also the development of new test processes and "maintenance" of existing ones that helps the whole industry.

Reviewer 3:

According to the reviewer, Idaho National Laboratory (INL) supports testing, evaluation, and validation successfully.

Reviewer 4:

The reviewer commented that INL continues to be a high-quality, state-of-the-art test facility that has the technical capabilities to fully evaluate all aspects of cells, modules, and packs with the acumen and experience to lead test manual developments for the DOE. It is somewhat unclear as to how benchmarking with ANL ties into the overall program objectives, the value this brings to the program itself, and the percentage of the program that is diverted to such activities. The program seemed already well integrated into many DOE and industry-oriented efforts.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer commented that impressive progress has been made through a project year and more valuable technical work will be accomplished in the near future.

Reviewer 2:
The reviewer said that there was good throughput of cells and the testing was of excellent quality. Also, the development of more test manuals is basically providing a full spectrum of cell testing methods.

Reviewer 3:
The reviewer observed that INL appears to be maintaining a proactive stance to emerging energy storage technologies and systems with the release of the 48V test manual, testing of relevant chemistries, and supporting fast-charging initiatives.

Reviewer 4:
The reviewer stated that INL has tested all USABC and other deliverables for validation of the progress of each program.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer pronounced the collaboration through industrial partners, universities, and the other national laboratories to be excellent.

Reviewer 2:
The reviewer commented that INL worked with many industry and academic groups in setting test manuals and with many suppliers in testing.

Reviewer 3:
The reviewer mentioned that INL collaborates with USABC members, developers, and other interested suppliers.

Reviewer 4:
The reviewer noted that coordination and collaborations are very 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.

Reviewer 1:
The reviewer remarked that future research is appropriate to mission.

Reviewer 2:
The reviewer commented that future research directions are positive and had no recommendations for changes.

Reviewer 3:
The reviewer noted that INL continues to support testing and validation in the future.

Reviewer 4:
The reviewer wanted to have more detail about future plans with regard to the project final objectives.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer responded yes and pointed out that all this work is very relevant to the overall DOE goal to reduce petroleum usage and reduce all environmental issues.

Reviewer 2:
The reviewer noted that the ability to give independent evaluation of cells gives industry the confidence to take them into product plans.

Reviewer 3:
The reviewer remarked that all efforts are highly oriented toward supporting the DOE mission of petroleum displacement.

Reviewer 4:
The reviewer stated that the continuation of verification of new developments supports DOE's objectives.

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

Reviewer 1:
The reviewer asserted that the laboratory capabilities and resources are sufficient.

Reviewer 2:
The reviewer noted that all resources are very sufficient except the industrial support for the program.

Reviewer 3:
The reviewer commented that there are enough resources to run existing facilities, but if the facility could be expanded, they could lower the backlog or keep cells on test longer.

Reviewer 4:
The reviewer stated that current resources appear to be sufficient; however, increasing a portion of the budget to support WFO agreements with industry would be advisable.

Presentation Number: es203
Presentation Title: Battery Safety Testing
Principal Investigator: Leigh Anna Steele (Sandia National Laboratories)

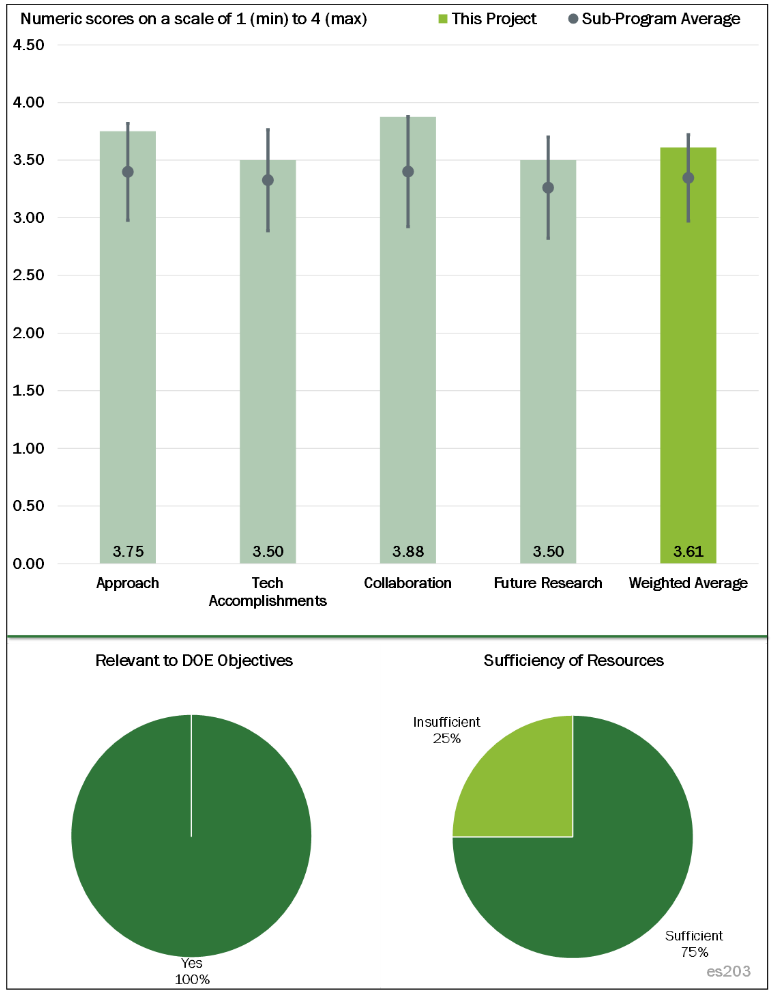

Figure 3-18 – Presentation Number: es203 Presentation Title: Battery Safety Testing Principal Investigator: Leigh Anna Steele (Sandia National Laboratories)

Presenter

Leigh Anna Steele, Sandia National Laboratories

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer commented that SNL and this program team continue to provide the gold standard in safety testing. The approaches to safety testing are sound, and the continued focus on providing and updating test manuals and best practices is highly relevant and inherently integrated with other testing efforts.

Reviewer 2:

In the reviewer's view, the research is a key facet of all DOE battery work and the gold standard worldwide.

Reviewer 3:

The reviewer said that SNL works with USABC developers to meet abuse testing protocol and targets.

Reviewer 4:

The reviewer stated that the goal of the project is well defined but not well designed due to unpredictable circumstances. The approach to understanding thermal behavior of cell or module and pack is of great importance. However, the designed experiment really depends on how to procure those cells from industry. Most of the results gained from tests are very limited by cell or pack design, including cell chemistry.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer noted that SNL has tested all USABC deliverable cells and modules to validate abuse performance.

Reviewer 2:
The reviewer commented that the new test manual will be a boon to all and did not come easily. Propagation is an important topic and while implementation dependent, the research team has shown some mitigation techniques. The new large site is a great addition to the existing capabilities.

Reviewer 3:
The reviewer asserted that there were two critical technical accomplishments, the first being internal short circuit stimulation using laser initiation and the second being thermal failure propagation studies with Al and Cu spacers. Impressive results have been made through this year. However, the reviewer still needed to understand why the PI chose the metal foil spacers rather than other materials that can be used as a heat sink more widely.

Reviewer 4:
The technical accomplishments are incredibly positive and appear to have kept pace with the increasing demands associated with increasing energy density, faster charge rates, and the screening of new materials. The one aspect of “safety” that could be improved would be an attempt to quantify the “value” and/or cost in terms of $/kWh, based upon some heuristic with guidance from industry. It seems difficult to identify a quantitative value proposition for safety-related sub-components, yet these will be fundamental to life safety as EVs become more prevalent in the United States.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that there was excellent collaboration.

Reviewer 2:
The reviewer remarked that just the work with USABC alone shows great collaboration on important work.

Reviewer 3:
The reviewer stated that high quality collaborations are already in place and the work is well coordinated with USABC efforts.

Reviewer 4:
The reviewer noted that SNL collaborates with USABC and cell and module developers successfully.

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.

Reviewer 1:
The reviewer found the future research to be appropriate given their funding and mission.

Reviewer 2:
The reviewer commented that quality future research has been proposed, particularly efforts to feed data back into models to refine these for crashworthiness, etc.

Reviewer 3:
The reviewer stated that SNL plans to continue to support USABC, test deliverable cells, and provide support for future activities.

Reviewer 4:
The reviewer mentioned that the future plan must be more organized with regard to the final project objectives. It is not very clear how to reach the project goal with all these spot-to-spot activities.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said yes, and noted that the thermal characterization with two unique approaches is very impressive and can be easily applicable to the DOE final objectives.

Reviewer 2:
The reviewer stated that safety is always relevant, especially so in batteries.

Reviewer 3:
The reviewer observed that safety testing is paramount to ensuring that the widespread adoption of EVs will not be accompanied by public relations (PR) nightmares and major shifts in public opinion away from a desire to displace petroleum.

Reviewer 4:
The reviewer stated that safety of EV batteries is important to make EVs acceptable.

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 it looks as if all resources are sufficient to do this project. The reviewer stated that SNL is very oriented to do this kind of thermal characterization at many different levels of batteries and provides critical information to the public.

Reviewer 2:
The reviewer said that the laboratory capabilities and resources are sufficient.

Reviewer 3:
The reviewer commented that the team could possibly use another person on staff to help with the backlog, but sufficient is a good description.

Reviewer 4:
The reviewer suggested that, in order to be prepared for the eventual inflection point of EV adoption (perhaps in the next 2-3 years), additional resources should be devoted toward safety testing (particularly testing of imported batteries that will likely become commonplace due to a lack of domestic manufacturing capacity).

Presentation Number: es204
Presentation Title: Battery Thermal Characterization
Principal Investigator: Matthew Keyser (National Renewable Energy Laboratory)

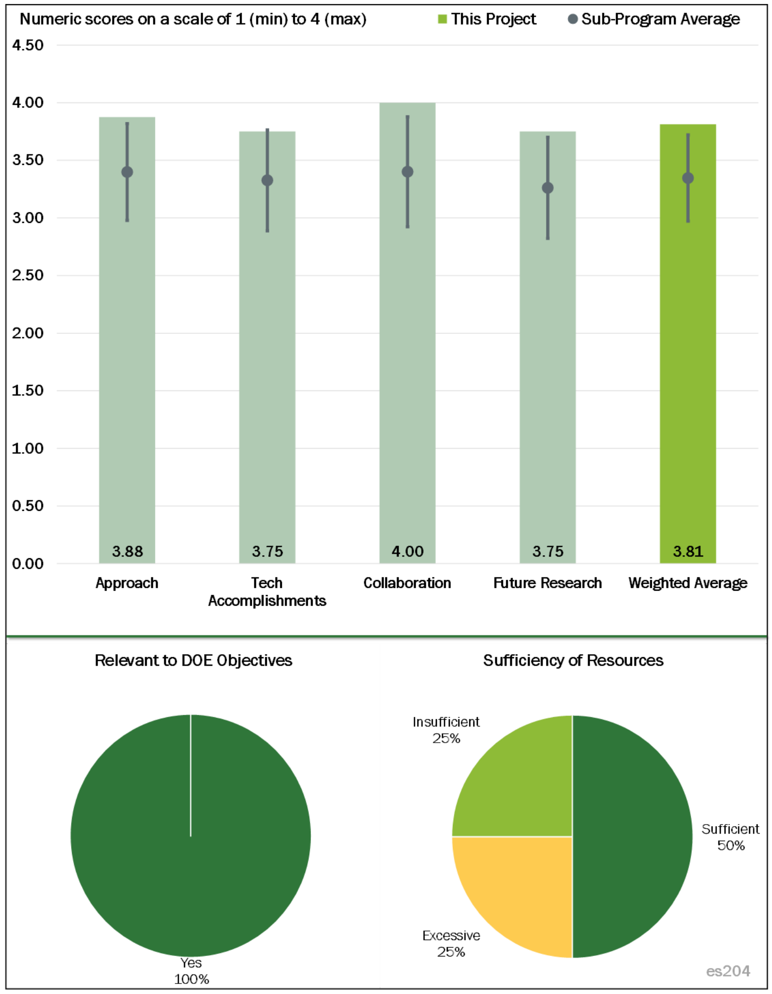

Figure 3-19 – Presentation Number: es204 Presentation Title: Battery Thermal Characterization Principal Investigator: Matthew Keyser (National Renewable Energy Laboratory)

Presenter

Matthew Keyser, National Renewable Energy Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that all these technical approaches are greatly welcome to the battery industry to understand battery failure mechanisms thermally over the life of the battery. The tools, which include calorimeters, thermal imaging, and others, are impressive.

Reviewer 2:

The reviewer asserted that the project has world class equipment and staff used to good advantage for science and industry.

Reviewer 3:

The reviewer commented that there is a high quality approach to this program. The thermal aspects of batteries are fundamental, particularly for the higher energy and faster charging cells that are on the DOE roadmap. The reviewer stated there was very interesting emerging work on the thermal implications of fast charging.

Reviewer 4:

The reviewer observed that thermal testing of cells, modules, and packs and testing results provide needed feedback to battery suppliers.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer noted that progress and technical contributions made through the project year are excellent and expected to see more valuable technical aspects accomplished in the near future.

Reviewer 2:
The reviewer commented that the project was able to show how entropy impacts batteries and supercapacitors and could demonstrate the impact of specific additives that help users tune products at the pack and cell level. It is a nice mix of application and science.

Reviewer 3:
The reviewer stated that the accomplishments include all USABC battery thermal characterizations and supporting information.

Reviewer 4:
The focus on incorporating modeling with experimental data has been a nice evolution of this program. It would be interesting to see more solid electrolyte cell testing and studies. It would also be useful for DOE to consider engaging NREL with ongoing projects at an earlier stage (i.e., understanding the thermal performance in smaller cells and during the cell design process).

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that there was excellent collaboration through industrial partners, universities, and other national laboratories.

Reviewer 2:
The reviewer stated that there were many collaborators and benefits going both ways.

Reviewer 3:
The reviewer opined that there was outstanding collaboration and coordination, particularly for such a relatively small budget.

Reviewer 4:
The reviewer enthused that the collaboration with USABC members and battery developers is excellent.

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.

Reviewer 1:
The reviewer commented that the correlation between experimental work and the battery usage model with the calorimeter is great. The reviewer looked forward to seeing more applicable result in the future.

Reviewer 2:
The reviewer found the funding level to be appropriate for the area they are assigned to cover.

Reviewer 3:
The reviewer said that the thermal aspects of fast charging are very timely and relevant.

Reviewer 4:
The reviewer stated that the continuation of USABC and partners is well planned.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer responded yes, and pointed out that all this work is very relevant to the overall DOE goal to reduce petroleum usage and reduce all environmental issues.

Reviewer 2:
The reviewer observed that heat transfer and heat generation are key to function, longevity, and safety for batteries and so this is key to electrifying vehicles for petroleum reduction.

Reviewer 3:
The reviewer asserted that a comprehensive understanding of the thermal implications of EV batteries is required for widespread adoption.

Reviewer 4:
The reviewer said that the NREL testing and characterization battery provides the road map to long lasting 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 all resources are very sufficient.

Reviewer 2:
The reviewer remarked that they get the job done with what they are given, probably sufficient funding.

Reviewer 3:
The reviewer concluded that the testing facility and resources are sufficient.

Reviewer 4:
The reviewer suggested that it would be useful for DOE to consider engaging NREL with ongoing projects at an earlier stage (i.e., understanding the thermal performance in smaller cells and during the cell design process).

Presentation Number: es207
Presentation Title: Towards Solventless Processing of Thick Electron-Beam (EB) Cured Lithium-Ion Battery Cathodes
Principal Investigator: David Wood (Oak Ridge National Laboratory)

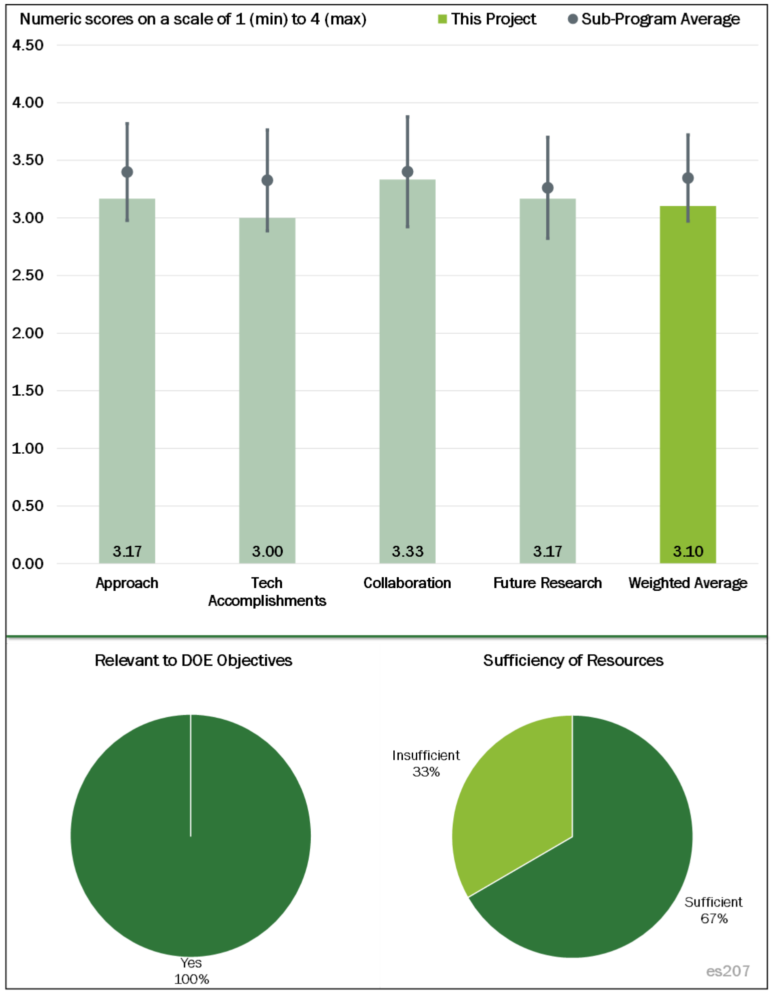

Figure 3-20 - Presentation Number: es207 Presentation Title: Towards Solventless Processing of Thick Electron-Beam (EB) Cured Lithium-Ion Battery Cathodes Principal Investigator: David Wood (Oak Ridge National Laboratory)

Presenter

David Wood, Oak Ridge National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer noted that the approach is feasible, and if it is successful, it could significantly improve manufacturing efficiency.

Reviewer 2:

The reviewer asserted that there seem to be many technical barriers, including, in no particular order: excluding oxygen from the curing process, getting proper size particles of the resin, and refining an appropriate method of coating the proposed thick coatings without a solvent.

There is also the barrier of convincing a battery manufacturer to adopt a technology that would require major modifications in the conventional manufacturing processes. All of these issues are mentioned in the presentation, but the route to solving them is sometimes vague.

Reviewer 3:

The reviewer stated that the approach is effective in removing or eliminating any solvent (NMP and water) from the process of electrode fabrication. This could lead to a substantial reduction in EV cost.

The reviewer pointed out that it would have been nice to include a comparison to the similar DOE project, ES132 (“Utilization of UV or EB Curing Technology to Significantly Reduce Costs and VOCs”), which finished in 2014 with ORNL as a partner, because the reviewer wanted to know whether this work builds on that previous effort. [DOE Program Clarification: Although ES132 and ES207 share similarities, these projects are not directly related.]

Reviewer 4:
The reviewer stated that the project aims to develop alternative electrode processing procedures (solvent-less electron beam curing) to significantly decrease EV battery cost and increase electrode thickness (and therefore energy density). Milestones and go/no-go decisions are sparse. The approach seems to be complicated and dependent on success of many independent subprojects.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer referenced prior comments, and stated that the project does seem to have made progress in many areas.

Long-term cell performance data and detailed analysis of the proposed cost savings still need to be done.

The importance of the goal of reduced cost is well recognized, but the specific data, calculations, and modeling to support the presentation's assertions as to the savings that may be realized with EB technology are limited.

Reviewer 2:
The reviewer observed that good progress was demonstrated and a lot of tasks were accomplished; the percent of completed tasks corresponded to the time line of the project. But, some important tasks were not finished or not mentioned in the 2017 report. For example, the 2016 report demonstrated (Slide 27) that initial irreversible capacities for EB electrodes are more than two-fold larger compared to the baseline. The reviewer wanted to know how this issue was solved and whether this is the result of EB influenced by active material selection.

Reviewer 3:
The reviewer noted that significant progress has been made on improving coating properties. However, progress toward their main objective of significant process energy savings was unclear to the reviewer. Additionally, electrochemical performance seems to suffer with low capacity retention observed for samples.

Reviewer 4:
The reviewer mentioned that progress has been made in addressing previous year challenges, such as poor adhesion of coated electrodes. However, it is not clear if the impact on goals (cost) of the proposed solutions has been evaluated.

Reviewer 5:
The reviewer asserted that the team made some progress; however, it has not shown promising results yet. It looked to the reviewer as if the rate capability is not really better compared to the baseline shown on Slide 11.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that collaborative activities and involvement of each partner are clearly described.

Reviewer 2:
The reviewer observed that the program appears to be making good use of collaborations on various coating technologies and raw materials suppliers. Validation of this novel approach by a Top 3 cell producer should be performed to ensure a pathway to success and implementation.

Reviewer 3:
The reviewer commented that there seems to be good collaboration with industrial partners, especially those with expertise in coating and EB curing. The collaboration with materials' suppliers and battery manufacturers

is mentioned, but in less detail. The battery manufacturing partners are legitimate members of the battery community, but neither of them has a significant market position in batteries for consumer vehicles. XALT seems to be focusing on non-vehicular applications, such as marine uses, and Navitas is focused on military vehicles.

There is no mention of significant collaboration with academia or other national 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.

Reviewer 1:
The reviewer noted that the proposed future work does a good job of focusing on the issues identified in the presentation. It will be a challenge to combine coating and curing on a high speed line in a way that produces uniform, high-performing electrodes.

Reviewer 2:
The reviewer commented that future work should show improvements in current high-speed cured coatings to achieve better performance of electrodes and to transfer technology to mass production.

Reviewer 3:
The reviewer observed that mechanical integrity could be one issue because the binder could have weaker interfacial bonding with active materials from the electrostatic spray process.

Reviewer 4:
The reviewer commented that proposed future research lacks an economic analysis of their main objective—to reduce process energy via the EB curing process. Proposed future work seems to lack a clear process focus or decision points for process downselection.

Reviewer 5:
The reviewer opined that the project does not seem completely decided on one or two high-speed manufacturing methods to be explored. A significant amount of time that can be used for developing a method will be spent on looking for other potential methods.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said, yes, success should lead to reduction in EV costs and wider adoption in the market."

Reviewer 2:
The reviewer remarked that this project clearly supports DOE's goals. For electric drive vehicles to be adopted voluntarily (with minimum regulatory requirements) in the U.S. market, the cost of the batteries needs to be reduced and their specific energy and energy density need to be increased. High speed, solventless coating of thick electrodes (that perform well) will help meet these goals.

Reviewer 3:
The reviewer stated that decreasing process costs can lead to lower cell costs and hence accelerated vehicle electrification and therefore petroleum displacement.

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

Reviewer 1:

The reviewer commented that the project is accomplishing significant amounts of work considering the project funding ($350,000 for FY 2017). This reviewer observed a good job, and asserted that this is an efficient use of funds for amount of work performed.

Reviewer 2:

The reviewer noted that plans for future work, including evaluating other high-speed manufacturing methods, seem very ambitious for the amount of resources allocated to the project.

Reviewer 3:

The reviewer pointed out that this project is scheduled to receive less than half the funding allocated for the related project (ES164) on thick, low-cost electrodes produced with aqueous processing. ORNL is the lead on both projects so one assumes that the costs of labor and facilities are similar for the two projects. The presentations seem to indicate that the two projects are using some of the same facilities. The challenges facing the two projects are of similar magnitude, and this reviewer added that, if anything, this EB project is more challenging.

The reviewer said that if the Aqueous Processing project is appropriately funded, then this project is probably underfunded. Of course, if this project is properly funded, then the Aqueous Processing project may be overfunded.

Presentation Number: es220
Presentation Title: Addressing Heterogeneity in Electrode Fabrication Processes
Principal Investigator: Dean Wheeler (Brigham Young University)

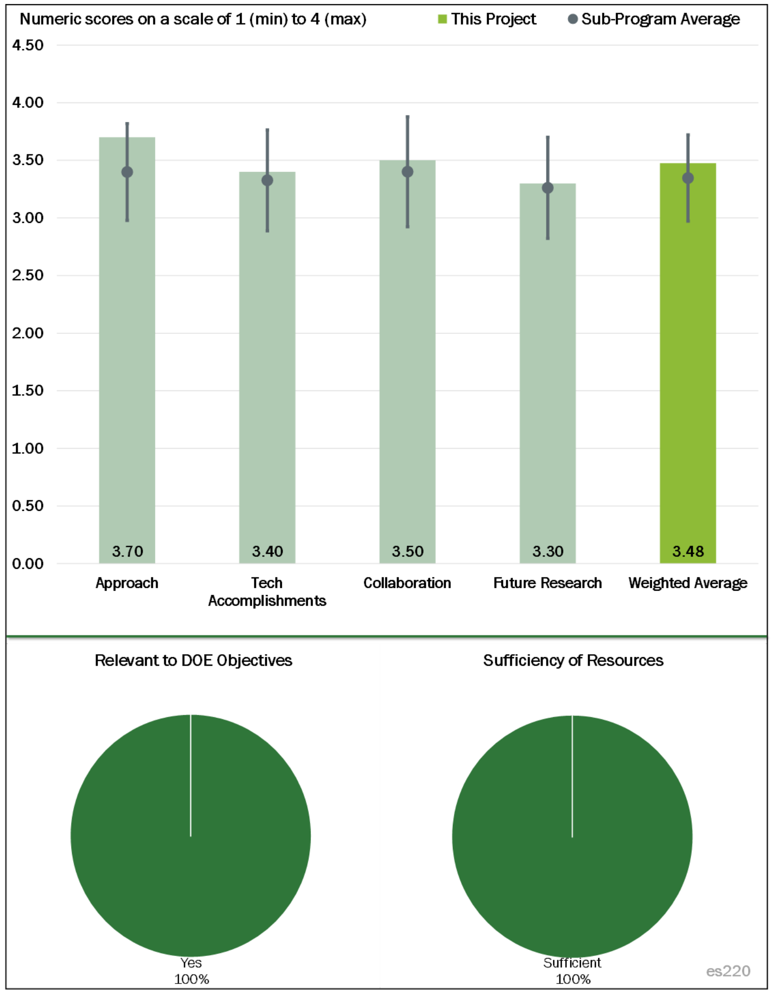

Figure 3-21 – Presentation Number: es220 Presentation Title: Addressing Heterogeneity in Electrode Fabrication Processes Principal Investigator: Dean Wheeler (Brigham Young University)

Presenter

Dean Wheeler, Brigham Young University

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer remarked that Wheeler has done an outstanding job coming up with a new technique that may ultimately address industrial needs for improving electrode fabrication. Development of a flexible probe will make the technique more feasible. Coming up with a model that goes from fundamentals to electrode fabrication is very ambitious.

Reviewer 2:

The project is bringing deep understanding to electrode processing and developing tools that industry can use. The reviewer found the presentation very effective and the ideas being pursued, including the model for manufacturing, very compelling. The reviewer thought that this project was very good and has the right balance between the need to help industry versus not repeating what industry does best.

Reviewer 3:

The reviewer stated that the PI has an excellent approach to this challenging problem.

Reviewer 4:

The reviewer commented that measuring the conductivity of anode and cathode electrodes is a good measure of heterogeneity and is also critical for battery performance so this is a good approach. The attempt to correlate structural features with conductivity seems reasonable but is not yet yielding good results.

Reviewer 5:

The reviewer pointed out that the PI designed and fabricated a micro-sensor using microfabrication technology. The conductivity sensor was tested to measure the local surface and bulk conductivities of a coated electrode web. Modeling was also used to estimate the microstructure. In-line conductivity measurement could be used as a quality control tool in the production line. The micro-probe is a great approach for the task. The design is simple to fabricate, easy to implement, and feasible for in-line applications.

The argument is the representation of the measurement of the limited area for the whole electrode web, which is related not only to the homogeneity of the electrode coating but also the morphology of the electrode surface. The PI should utilize the modeling tool to optimize the design, especially the size of the probe.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer praised the PI's outstanding job improving his technology. He has advanced his probe by making it flexible, which could allow its use in industry. He has provided a highly plausible explanation for the variability in cathode conductivity. And, his highly ambitious model for electrode fabrication has made good progress.

Reviewer 2:

The reviewer saw steady progress on this problem. The PI is focusing on techniques that can be adapted in most laboratories. The modeling effort has refocused on a new method, but it was not clear to the reviewer that it will be successful. It is not clear what properties will be obtained from the acoustic technique.

Reviewer 3:

The reviewer found it interesting that ionic conductivity increases with cycling while electronic conductivity decreases.

Reviewer 4:

The reviewer noted that the project progressed as planned. The flex probe was developed and made. The measurement by the flex probe was in good agreement with that of the non-flex counterpart. A mathematical model for particle mixing was established and tested.

The area that the PI could improve is that the fix pressure imposed on the electrode web may not be the best solution. The PI should test the change of resistance with the change of pressure exerted on the probe and the electrode. The reviewer suspects the resistance-force curve would change between electrodes because the contour of the electrode surface and hardness of various battery material would have significant impacts.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer mentioned that the PI has adequate collaborators ranging from the battery industry (e.g., A123 and LG) to academia and national laboratories, which cover the ground of both scientific collaboration and application.

Reviewer 2:

The reviewer saw good collaboration and exchange of materials and expertise with some leading battery developers and material suppliers

Reviewer 3:

The reviewer observed that the PI has extensive collaborations across industries and laboratories.

Reviewer 4:

The reviewer stated that there are a good number of collaborators, but it is not clear which collaborators are doing what and how involved they are in the project.

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

Reviewer 1:
The reviewer said the PI has an excellent plan.

Reviewer 2:
The reviewer found the work to be relevant and well thought out. In the near future, it will be critical for the PI to begin more intensive collaborations with industry. It is not at all clear that the processing conditions leading to greater or lesser heterogeneity that are being discovered with laboratory made electrodes have any relevance to real commercial products. The reviewer hoped that the PI can begin to provide processing feedback and guidance soon.

Reviewer 3:
The reviewer saw a clear path forward for this work. Specific problems that may be encountered and what work-arounds might be available were not discussed much.

Reviewer 4:
The reviewer observed that the proposed future work covers most of the critical areas, especially the correlation between the modeling results and experimental data.

The PI is encouraged to do more work on the representation of the results from a micro-size probe to a large electrode.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer agreed that this project is relevant because electrode homogeneities could be significant contributors to cell fade now and will likely become even more important as DOE and the car manufacturers begin to introduce fast charge capabilities. Another factor impacting electrode non-uniformities is the push to thicker electrodes, which could exacerbate these issues.

Reviewer 2:
The reviewer observed that there is a plausible and well-defined pathway to take this work—either measurements or models—to industry. This would allow a method for improving the homogeneity of electrodes, which should lead to longer lived cells.

Reviewer 3:
The reviewer said yes. The project could lead to better battery production quality control, which is one of the critical area of reaching low-cost and reliable production.

Reviewer 4:
The reviewer found the PI's work to be 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 remarked that the PI has done a good job of living on the cheap.

Reviewer 2:
The reviewer noted that PI can access adequate resources to conduct the proposed tasks.

Reviewer 3:
The reviewer stated that the resources are appropriate for the work done and a good value for the investment here.

Reviewer 4:
The reviewer said that the resources are sufficient.

Presentation Number: es225
Presentation Title: Design and Synthesis of Advanced High-Energy Cathode Materials
Principal Investigator: Guoying Chen (Lawrence Berkeley National Laboratory)

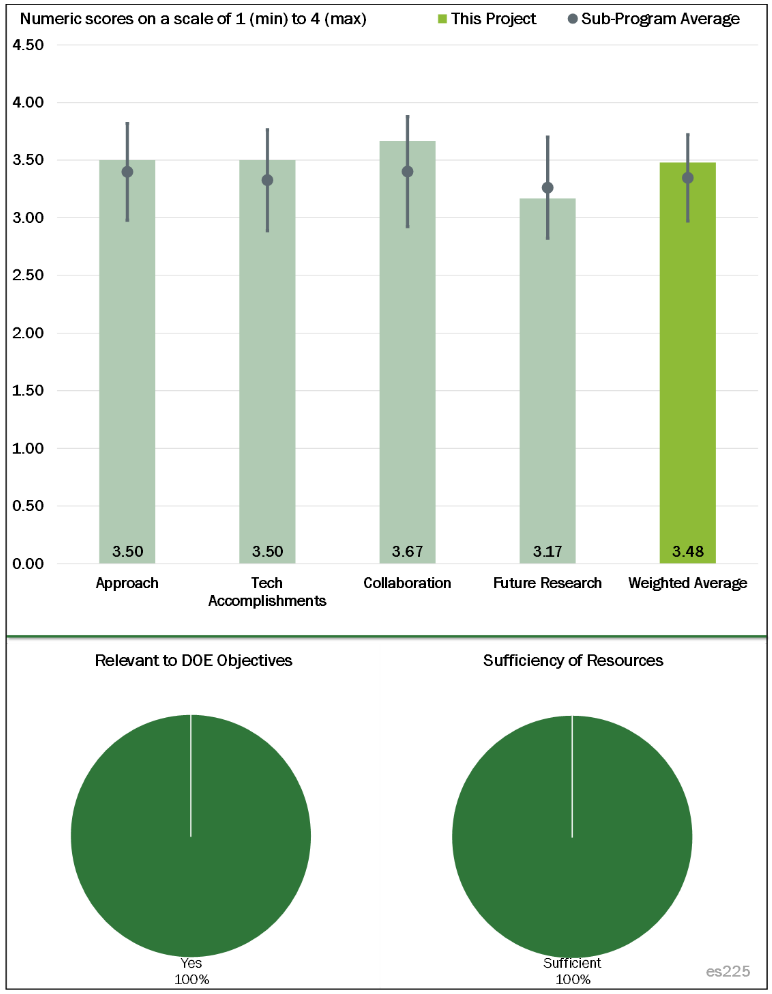

Figure 3-22 - Presentation Number: es225 Presentation Title: Design and Synthesis of Advanced High-Energy Cathode Materials Principal Investigator: Guoying Chen (Lawrence Berkeley National Laboratory)

Presenter

Guoying Chen, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer pointed out that the PI has an excellent approach. While the approach is rather simple, the PI has found an important niche to work in and be very productive.

Reviewer 2:

The reviewer noted that high energy cathode materials are still needed for the next generation of LIB development. This project tackles some of these materials with Li-excess transition metal oxide structures to understand their chemical and crystal structure stability as a function of composition and temperature in order to understand the origins of performance limitation. Through collaboration, a variety of characterization techniques was used to help elucidate the mechanisms related to degradation and develop rational design of such materials for improved performance.

The project seems to take a logical approach to address challenges related to interfacial stability issues. The analysis and synthesis of the experimental data into a coherent understanding of the issues are still premature to give any useful guidance for further work. The PI should develop a more robust hypothesis to help analyze the data and develop a rationale to elucidate what mechanism dominates the limitation on performance.

Reviewer 3:

The reviewer stated that this was interesting research to correlate synthesis with Li-excess cathode morphology (shape, size, and exposed surfaces) and performance. The goal is to achieve rationalized design of material.

The reviewer asked that the PI please consider more direct comparison with modeling.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer commented that the PI developed well-formed crystals of materials that enable studies otherwise impossible.

Reviewer 2:
The reviewer found the selection of a single valence transition metal compound doped with niobium to be a clever approach. However, the changes in the phase transformation are much more complex than originally thought. With a significant amount of work in the research community on NMC cathodes, a coherent understanding of the cathode structure stability remain lacking. Using a systematic approach is appealing. However, a comprehensive understanding remains challenging. It is not clear if this project would be able to accomplish this objective.

This reviewer would like to encourage the investigator to develop a more tangible hypothesis to guide the work so that the systematic approach can be realized. The reviewer expressed the sentiment of looking forward to more accomplishments as the research progresses.

Reviewer 3:
The reviewer acknowledged that extensive work was performed by the research team. However, the summary is rather vague. The reviewer asked if this comprehensive study can provide some conclusive remarks on which surface, size, or shape is preferred.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that the PI has extensive collaborations across the laboratory system. The PI is very effective at leveraging her work.

Reviewer 2:
The reviewer found the collaboration with the characterization groups to be excellent and encouraged more collaboration with theorists to develop better hypotheses for experiments. A more focused systematic approach is the right track for better outcomes.

Reviewer 3:
The reviewer noted that this project involved extensive 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.

Reviewer 1:
The reviewer stated that an aggressive plan is being put forward.

Reviewer 2:
The reviewer inquired if one can predict and correlate materials synthesis and processing methods with the final structures and properties.

Reviewer 3:
Although the proposed future work seems logical and necessary, it did not appear to the reviewer that there was clear guidance to effectively tackle the challenges. This deficiency also was reflected in the data analysis

because no clear guidance was developed to tackle the issues that caused the structure instability in the phase transformation.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer acknowledged that this research is very much related to petroleum displacement as it will enable higher energy density batteries.

Reviewer 2:

With model crystals there is always a question as to relevance, but the reviewer thought that the PI has worked to effectively address this issue.

Reviewer 3:

The reviewer asserted that finding a stable high-energy cathode material is critical for the development of the next generation of LIBs. This project directly feeds to the advancement of this objective. However, without a clear guidance for improving the search of a reliable cathode and mechanism to stabilize the performance, the impact of this work is undermined.

Finding a stable high-energy cathode material is critical for the development of the next generation of the LIBs. This project directly feeds to the advancement of this objective. However, without a clear guidance for improving the search of a reliable cathode and mechanism to stabilize the performance, the impact of this work is undermined.

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 sufficient.

Reviewer 2:

It was not clear to the reviewer what additional resources the investigator would be seeking to gain better knowledge and improve the impact of this project. The existing support should be sufficient for carrying out the current and future work as explained.

Presentation Number: es226
Presentation Title: Microscopy Investigation on the Fading Mechanism of Electrode Materials
Principal Investigator: Chongmin Wang (Pacific Northwest National Laboratory)

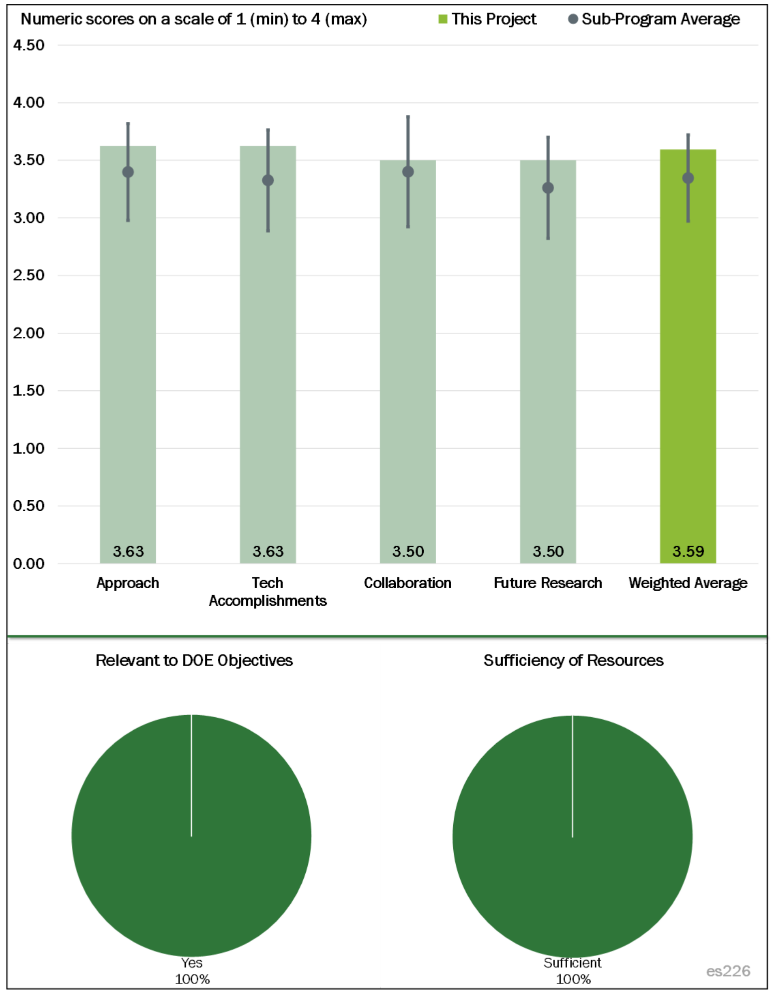

Figure 3-23 - Presentation Number: es226 Presentation Title: Microscopy Investigation on the Fading Mechanism of Electrode Materials Principal Investigator: Chongmin Wang (Pacific Northwest National Laboratory)

Presenter

Chongmin Wang, Pacific Northwest National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer stated that *in situ* and in-operando HRTEM is a unique and effective tool to study atomic scale structure and morphology of electrodes. It is very well suited to address the barriers.

Reviewer 2:

The reviewer stated that there was outstanding development of technologies that provide critical data for understanding battery materials.

Reviewer 3:

According to the reviewer, the project covers a variety of battery problems, from high-voltage cathodes in LIBs to Li-air systems. Characterizing surface and interfacial phenomena using highly sophisticated *ex situ* and *in situ* tools is a good approach. Establishing collaborations is listed as part of the approach; however, the collaborators are only providing materials and support for synthesis.

The project covers a variety of battery problems, from high-voltage cathodes in LIBs to Li-air systems. Characterizing surface and interfacial phenomena using highly sophisticated *ex situ* and *in situ* tools is a good approach. Establishing collaborations is listed as part of the approach, however the collaborators are only providing materials and support for synthesis.

Reviewer 4:

The reviewer commented that the general approach is excellent, but it would be helpful to have seen more detailed steps. For example, for the progression of materials, the reviewer asked what additional studies might be made, and so on.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer loved the data showing liquid penetrating secondary particles. Intragranular cracking as a function of voltage is also wonderful and would greatly benefit from collaboration with theory. There are many other excellent accomplishments.

Reviewer 2:
The reviewer noted that the PNNL group led by Dr. Wang has done some very interesting work on charging induced intragranular cracking and the SEI of layered cathode materials using advanced electron microscopy (EM) techniques. These works are sharply focused on challenges stated in the overview, the fading mechanism of electrodes.

Reviewer 3:
The reviewer posits that the discovery of intergranular cracking as a function of the charging potential range is very important.

Reviewer 4:
The reviewer opined that this project partly overlaps with ES085 and possibly others. The reviewer added that it would be good to have a better interaction among these groups. The electrolyte also becomes depleted at the anode, and this reviewer suggested that it would be good to connect these degradation phenomena. The reviewer further recommended that the longer cycling effect of the Al_2O_3 coating should be addressed (e.g., coating lithiation and reactivity, and electronic properties).

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that the PI has a long list of collaborators including national laboratories, universities, and industrial companies. The reviewer would like to encourage the group to develop collaboration with institutes where characterization techniques are complementary to EM, such as synchrotron X-rays.

Reviewer 2:
The reviewer pronounced the collaborations to be excellent.

Reviewer 3:
The reviewer enthused about terrific collaboration.

Reviewer 4:
The reviewer referenced prior comments, and said that a more integrated collaboration beyond just exchange of materials and support for synthesis would be helpful for the project.

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

Reviewer 1:
The list of future work involves understanding critical battery properties. The reviewer was hugely impressed and looking forward to this future work.

Reviewer 2:
The reviewer commented that the proposed future work is well planned to tackle the remaining challenges and barriers within the scope of EM techniques.

Reviewer 3:
The reviewer found the listed objectives for FY 2018 to seem somehow disconnected. The first listed item for FY 2018 is unclear.

Reviewer 4:
In addition to the proposed future work, the reviewer said it would be important to see the effects of preconditioning of the electrode by restructuring the surface as shown by Kostecki in this year's review to see if there are beneficial effects on particle cracking.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer commented that this project is very well designed and conducted to support DOE objectives, with more fundamental approaches to tackle the capacity fading problems of electrodes for LIBs.

Reviewer 2:
The reviewer noted that the mechanism of cathode impedance growth is of great importance to DOE objectives.

Reviewer 3:
The reviewer responded, “Yes.” Characterization of interfacial phenomena is a good way of understanding the behavior of battery materials and developing strategies to improve them, therefore supporting the objective of petroleum displacement.

Reviewer 4:
The reviewer said that the PI’s samples come from a wide variety of sources, from universities to General Motors.

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

Reviewer 1:
The reviewer observed that the resources seem sufficient for the proposed objectives. The goals complement other efforts

Reviewer 2:
The reviewer stated that this is a strong team in the EM field.

Reviewer 3:
The reviewer said that the PI develops state-of-the-art technology.

Presentation Number: es231
Presentation Title: High-Energy Density Lithium Battery
Principal Investigator: Stanley Whittingham (Binghamton University-SUNY)

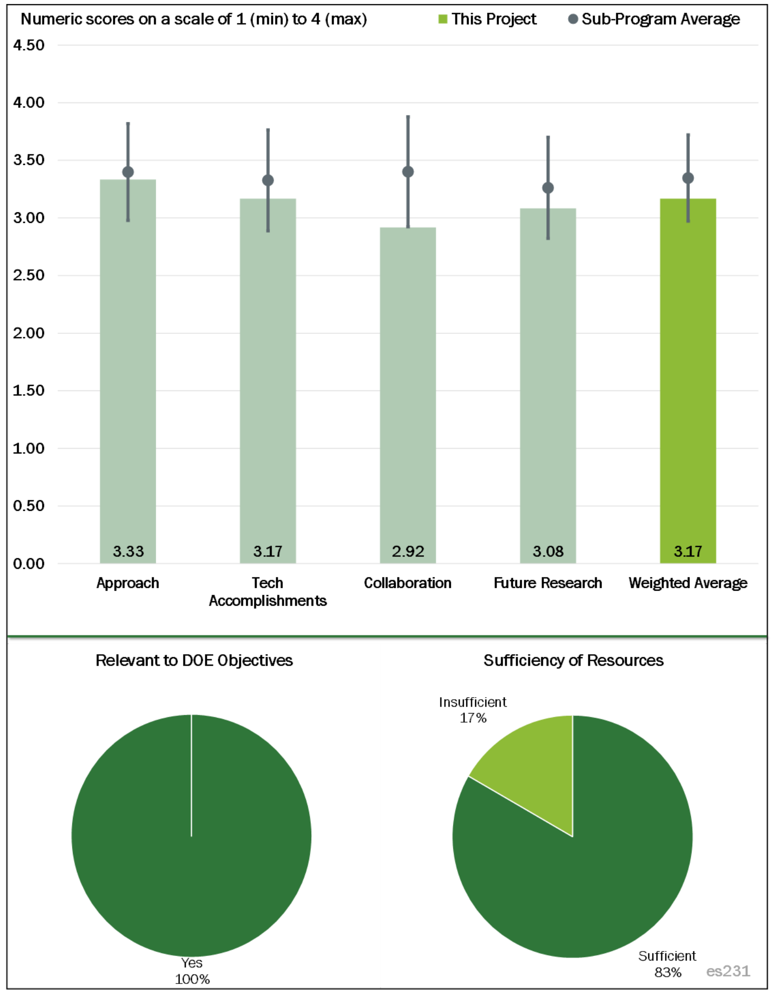

Figure 3-24 - Presentation Number: es231 Presentation Title: High-Energy Density Lithium Battery Principal Investigator: Stanley Whittingham (Binghamton University-SUNY)

Presenter

Stanley Whittingham, Binghamton University-SUNY

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer remarked that the objective of this task is to identify and develop new, high specific energy and energy density anode and cathode materials for improving the energy densities and costs of LIBs. For improving the energy density of the graphite anode, conversion reaction materials (especially tin-based alloys [Sn_xFe]) are safer and lower cost; they also have lower volume expansion and two-three times volumetric and specific capacities. However, this material has high irreversible capacity and requires pre-lithiation, which is a challenge. Similar materials (Cu-tin alloys, for example) were studied for several years at ANL with little at the end.

Likewise, for improving specific energy of the conventional intercalation (one Li) cathodes, two types of conversion/intercalation cathodes with multiple lithiums (i.e., copper (II) fluoride [CuF_2] with twice the specific energy of LCO and vanadium phosphate [$VOPO_4$] with 1.5 times the capacity of LFP) are being developed. While achieving good reversibility and durability with metal fluorides is a huge challenge, the vanadyl phosphate cathodes have been under development for several years without much success. Even though they have higher capacity, the voltage profile is sloping and the discharge voltages are much lower than today's Li-ion cathodes. Overall, the approach has limited novelty in materials, but the project is well designed to examine feasibility of these materials and integrated with the DOE goals.

Reviewer 2:

The reviewer highly recommended developing the following to further improve energy density of current LIBs: non-carbonaceous anode materials and ways to maximize layer cathode materials; or a new class of cathode materials. This reviewer asserted that project objectives are well aligned with this.

Reviewer 3:

The reviewer said that the approach is good and is attempting to solve one of the major technical barriers for EVs—the low volumetric energy density of today's LIBs. The team is focusing on cutting in half the volume of the anode and identifying a cathode that has a capacity over 200 Ah/kg. Conversion reaction anode materials and cathode materials that react with less than or equal to 1 Li per transition metal under investigation are high risk, but are also high payoff if successful.

Reviewer 4:

The reviewer commented that while the concept is excellent, the candidates are limited. Vanadium oxyphosphate does not look very attractive. The reviewer asked why not continue to pursue CuF_2 by preventing Cu^{2+} dissolution.

Reviewer 5:

The reviewer observed that DOE should be funding more projects like this that are exploring novel active materials. We need to have new materials in the pipeline. The project does an excellent job incorporating background knowledge to efficiently move forward. The project may be too ambitious by working on both a new cathode and anode.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer reported that excellent progress was made this year. The team identified that cuprous transport on charging is a major issue for the long-term cycling ability of the CuF_2 system.

Reviewer 2:

The reviewer found the research to be candid and systematic with a clear path forward.

Reviewer 3:

The reviewer noted that good progress has been made with Sn_xFe anodes and CuF_2 and vanadyl phosphate cathodes in demonstrating their high capacities and reversibility in half-cells and later in laboratory full cells. CuF_2 shows high capacities of 350-450 mAh/g with reasonable rate capability. The capacity is further improved by blending with vanadyl phosphate (with lower voltages). But, the dissolution and migration of Cu to anode is a challenge in liquid or even in polymer electrolytes. The Sn_xFe anodes (Sn_2Fe and Sn_5Fe), synthesized by mechanical and polyol methods, show good capacities of 400-500 mAh/g and decent rate capability, but the improvement in specific energy over a graphite anode may be marginal due to their (Sn_xFe) higher anode potentials. Besides, these materials have high irreversible capacities (200%-300%), which necessitate a pre-lithiation.

Pre-lithiation with stabilized Li-metal powder has been attempted here, as was done by many in the past, but this is not a method viable for implementation in the Li-ion cell production. Performance of these anode and cathodes in full cells is not very encouraging either, even with this pre-lithiation.

Nevertheless, based on the challenges associated with these materials, the progress is deemed good and well directed toward the DOE goals.

Reviewer 4:

The reviewer would like to have seen data for $VOPO_4$ alone, particularly for the voltage profile, and asked whether it is really worthwhile to continue. The tin-iron-carbon anode may not be practical although it has a very high capacity. This reviewer also noted that the voltage is sloping too much even at low rates compared to that for graphite at the same extent of charge. The reviewer also observed at least 300 mV more positive, lowering the cell voltage by the same at very a low rate.

The reviewer understood that the rate capability and cycle performance are looking good overall for the alloy and composite anodes. The reviewer asked what the energy density of the cell built is, and why the data would not be normalized by weight or volume. Even at the extremely low rate, the upper plateau (greater than 3V) fades quickly. For continuing with this pair, some approaches of alleviating such shortcomings should be proposed.

Reviewer 5:

The reviewer pointed out that this project demonstrated some improvement in capacity and cycling stability of $VOPO_4$ cathode and Sn_yFe anode materials. However, the practical electrode density of a $VOPO_4$ cathode should be reported so that its volumetric capacity and energy could be compared with the state-of-the-art cathode materials. Also, even though the Sn_yFe anode material shows high capacity, it is not clear how much gain in terms of energy density is achieved by using the Sn_yFe-$VOPO_4$ couple. For this electrochemical couple to really work, effective methods of pre-lithiation also need to be established.

Also, the reviewer found that there are results that are exactly the same as in the previous year's report: page 11 right plot is the same with 2016 page 13; page 12 is exactly the same with 2016 page 15; page 13 is the same with 2016 page 16; page 15 is the same with Page 17; and Page 16 is the same with Page 19. This reviewer commented that very limited progress was achieved during one year if the reused results are excluded.

Reviewer 6:

The reviewer called this project "challenging," but stated that good progress has been made. The reviewer suspected that (given the challenges of this project) it will be difficult to be close to the performance of current materials and hoped that this does not reflect poorly on the project—as it is so important to work on these new materials. The reviewer did not think the overall project goals of full cell cycling are achievable in the remaining timeframe and suggested that you gave up too early on the CuF_2.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer noted that there are good, ongoing collaborations with the DOE Laboratories (BNL and ANL) in the characterization of the cathodes and with universities on compatible electrolytes. Efforts are underway to have industrial participation through the New York Battery and Energy Storage Technology Consortium (NYBEST).

Reviewer 2:

The reviewer commented that the State University of New York (SUNY) team has excellent collaboration with national laboratories (BNL and ANL), academia (University of Colorado, University of Michigan, and University of Rhode Island), and industry (NYBEST).

Reviewer 3:

The reviewer pointed out that collaboration could be extended and improved; however, because few people are working on such novel materials, it is harder to find partners.

Reviewer 4:

The reviewer suggested that it would be helpful to collaborate with industry to ensure availability and manufacturability of the proposed new electrode materials.

Reviewer 5:

The reviewer inquired as to where the data are from the collaborators. It appears many national laboratories are involved. The reviewer asked where the characterization data are.

Reviewer 6:
The reviewer asserted that it is difficult to see what each partner's contribution was.

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.

Reviewer 1:
The reviewer found the future plans to be logical and well thought out. They are designed to conclude the effort this year.

Reviewer 2:
The project is coming to an end in a few months. Plans in the next few months call for continuing the studies on the tin-iron-carbon composite, Sn_2Fe, to complete the characterization and on vanadyl phosphate, $LiVOPO_4$, to extend the cyclability beyond 100 cycles. Additional work will continue on the full cell Sn_2Fe//$LiVOPO_4$ to evaluate extended cycling and demonstrate alternative pre-lithiation processes and, to a lesser extent, on Cu fluoride to identify possible electrolytes. These studies are relevant to bringing the project to a closure and addressing DOE goals.

The project is coming to an end in a few months and the work planned in the next few months is continuing the studies: on the tin-iron-carbon composite, Sn_2Fe—to complete the characterization; on vanadyl phosphate, $LiVOPO_4$ to extend the cyclability beyond 100 cycles; on the full cell Sn_2Fe//$LiVOPO_4$ to evaluate extended cycling and demonstrate alternate pre-lithiation processes; and to a lesser extent on Cu fluoride, to identify possible electrolytes. These studies are relevant to bringing the project to a closure and address the DOE goals.

Reviewer 3:
The reviewer suggested that if the suggested chemistries really provide advantages in terms of energy density and not only capacity, they should be seriously examined.

Reviewer 4:
The reviewer wanted to have seen more efforts on CuF_2, focusing on such approaches as preventing dissolution.

Reviewer 5:
Although kudos were offered for stretching, the reviewer warned that the work was too ambitious for the remaining time. This reviewer suggested that the project focus on either the cathode or the anode.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that for widespread use of EVs and PHEVs, it is imperative that the LIBs be lightweight, compact, safe, and low-cost. The state-of-the-art materials are inadequate to fulfil these needs. High specific energy cathode and anode materials with low-cost are required to improve the specific energy for Li-ion cells, thus increasing the range for the vehicle and reducing overall cost for the battery. Specifically, the present volume intensive carbon anode needs to be replaced with a high energy density Li alloy anode, and the present cathodes with one Li intercalation need to be replaced with cathodes having more than one Li reaction per transition metal. This project addresses both these aspects to make LIBs more acceptable for EVs and PHEVs, which in turn reduces the petroleum dependence.

Reviewer 2:
The reviewer commented that to enhance the driving distance of EVs, some breakthroughs are needed to advance the energy density of a Li-ion cell. For that purpose, advanced anode and cathode materials are needed. This project aimed to develop alternative active materials that surpass current state-of-the-art active materials, layered Li-metal oxide cathodes, and carbonaceous anode materials.

Reviewer 3:
The reviewer responded yes. If the volume of the anode could be cut in half and the cathode could demonstrate a capacity of over 200 Ah/kg, then the cell energy density could be increased by over 50%. The technology would aid in DOE's goal of promoting EVs.

Reviewer 4:
The reviewer said yes.

Reviewer 5:
The reviewer asserted that this would be a very high energy couple, one necessary for a step change in LIB 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 remarked that the resources are adequate for the scope of the project.

Reviewer 2:
The reviewer stated that the resources are sufficient in order to successfully complete the effort in a timely manner.

Reviewer 3:
As stated previously, the reviewer said that this was a challenging, ambitious project. The reviewer did not mean to be discouraging. However, it would be difficult to complete this project with the budget and time established.

Reviewer 4:
The reviewer said that it looks like resources are sufficient.

Presentation Number: es232
Presentation Title: High-Energy Density Electrodes via Modifications to the Inactive Components and Processing Conditions
Principal Investigator: Vincent Battaglia (Lawrence Berkeley National Laboratory)

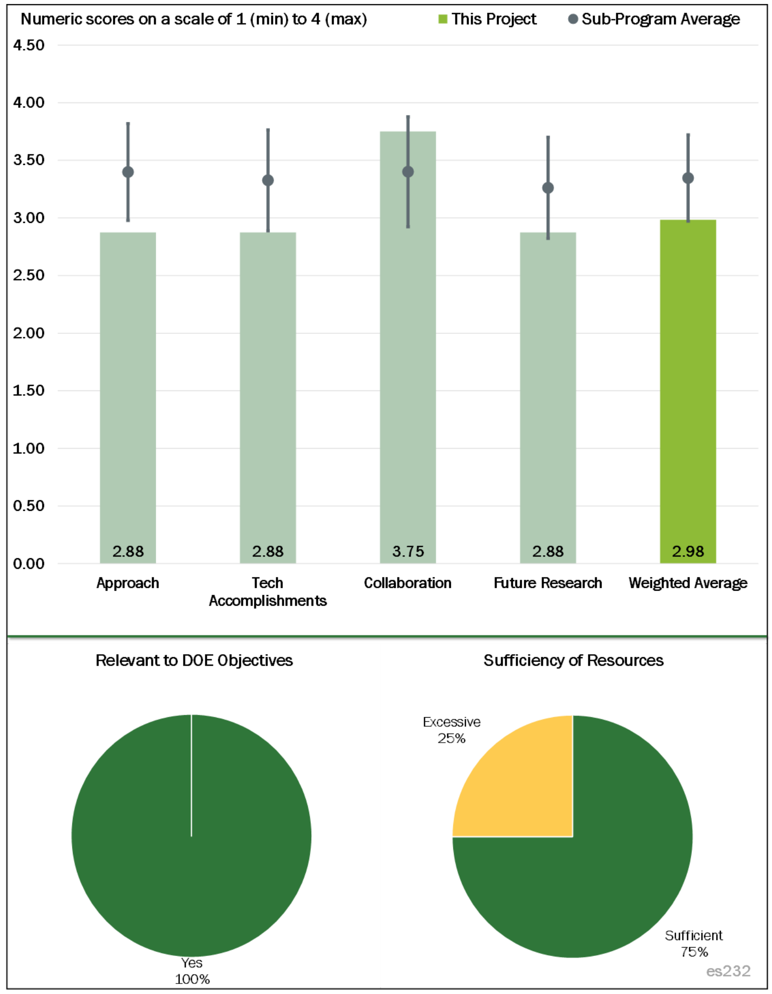

Figure 3-25 – Presentation Number: es232 Presentation Title: High-Energy Density Electrodes via Modifications to the Inactive Components and Processing Conditions Principal Investigator: Vincent Battaglia (Lawrence Berkeley National Laboratory)

Presenter

Vincent Battaglia, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer stated that the approaches are adequate to address one of the most critical problems associated with electrode production processes. Making thick and dense electrodes is important for making high energy cells. The PI tries to understand the impacts of fundamental material aspects on the electrode coating process.

Reviewer 2:

While the PI's overall goal is good, the reviewer remarked that the overall approach needs some improvement. It is not clear that the PI's choice of binders was focused on binders developed for thick flexible electrodes. It also looked like slurry mixing was not considered, which can be quite important for electrodes with low binder content. In general, it is not clear that the PI has the resources to adequately conduct this study or that this study should be conducted within the Advanced Battery Research (ABR) program.

Reviewer 3:

The reviewer expressed concern about the way this work is being carried out. Drying electrodes overnight and then evaluating their properties makes this work of limited interest. The critical value that national laboratories can bring to industry is to investigate processes and materials of relevance to industry, but then to explain the phenomena in terms of fundamental understanding. That is lacking in this project. The experiments that are being done are likely done by industry already, and the insight into the results is lacking. For example, material developers have dealt with NMC flattening during calendaring for the past 10+ years, and they have addressed the issue. They do not need to know that this is happening, but rather why and what can be done to prevent it in new materials.

Reviewer 4:
The project is addressing the important topic of electrode processing. Industry has largely followed an empirical approach. Science can help in a variety of ways, including making thick electrodes. However, the problem is that research effort at national laboratories needs to complement industrial efforts and this can be hard because industry is secretive. The reviewer thought that this project suffers from not being able to find this balance. The techniques used (cross section scanning electron microscope, bend test, etc.) seem rather routine, which is not to say they are not very useful. However, one wonders if this is repeating what industry already knows. The reviewer suggested that a deeper use of the amazing resources at the national laboratories to address the questions the PI proposed to answer.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
During the past year, the reviewer noted that the effects of calendaring on porosities at various temperature were studied. The mechanical properties of the electrode were evaluated again the polymer fraction and addition of carbon nanotubes. The electrode made under various conditions were made into half coin cells and tested. The performance of the electrode of various properties was tested.

The reviewer opined that the PI ought to extend the area of evaluation beyond calendaring, e.g., mixing process, viscosity of slurry, drying temperature, particle size of powder etc.

Reviewer 2:
The reviewer said that the work was good, but not particularly innovative or insightful.

Reviewer 3:
The reviewer referenced prior comments and described technical accomplishments and progress as okay, but not of particular interest or value to developers.

Reviewer 4:
The reviewer commented that the PI seemed to have not looked at his slides before the presentation. Thus, the reviewer found it hard to tell how much was the presentation versus how much was the accomplishments, but there seemed to be less detailed understanding and more reporting of what the project team found.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that number of collaborators was excellent, both within the BMR program and with outside firms like Daikin, Umicore, and Arkema.

Reviewer 2:
The reviewer noted that the PI has extensive collaborations. It is not clear why the PI is getting materials from secondary sources (e.g., separators from Brigham Young University [BYU]).

Reviewer 3:
The reviewer observed that the PI established adequate collaboration with researchers in academic institutions and material manufacturers and encourages the PI to collaborate with cell manufacturers.

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.

Reviewer 1:
The reviewer said that it is clear that the PI intends to address a number of issues resulting from the present effort.

Reviewer 2:
The reviewer noted that it looks as though the team has planned future research to improve their own electrode making ability and proposed that they focus on the "why" and aim to help industry more.

Reviewer 3:
The reviewer stated that the proposed future research covers the critical area of electrode process.

Reviewer 4:

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer asserted that the project is directly related to Li-ion cell production technologies. Cost effective and quality consistent production are key.

Reviewer 2:
The reviewer said the work is relevant.

Reviewer 3:
With the caveat that the project may be repeating what industry already knows, the reviewer thought that the premise of the project is good.

Reviewer 4:
The reviewer found the project to be extremely relevant as the ability to make high quality electrodes, especially high energy density electrodes, is critical to both laboratory and university PIs and to industry. Extreme high loading is critical for EVs, and it is good that the PI is working on this. But watch, the reviewer cautioned, as there are at least two very promising approaches: variable frequency microwaves and EB.

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 PI has adequate resources to conduct the proposed tasks.

Reviewer 2:
The reviewer stated that the resources are sufficient to examine the problem as the PI has planned.

Reviewer 3:
The reviewer found the resources to be quite high compared to other projects.

Presentation Number: es235
Presentation Title: Characterization Studies of High-Capacity Composite Electrode Structures
Principal Investigator: Michael Thackeray (Argonne National Laboratory) -

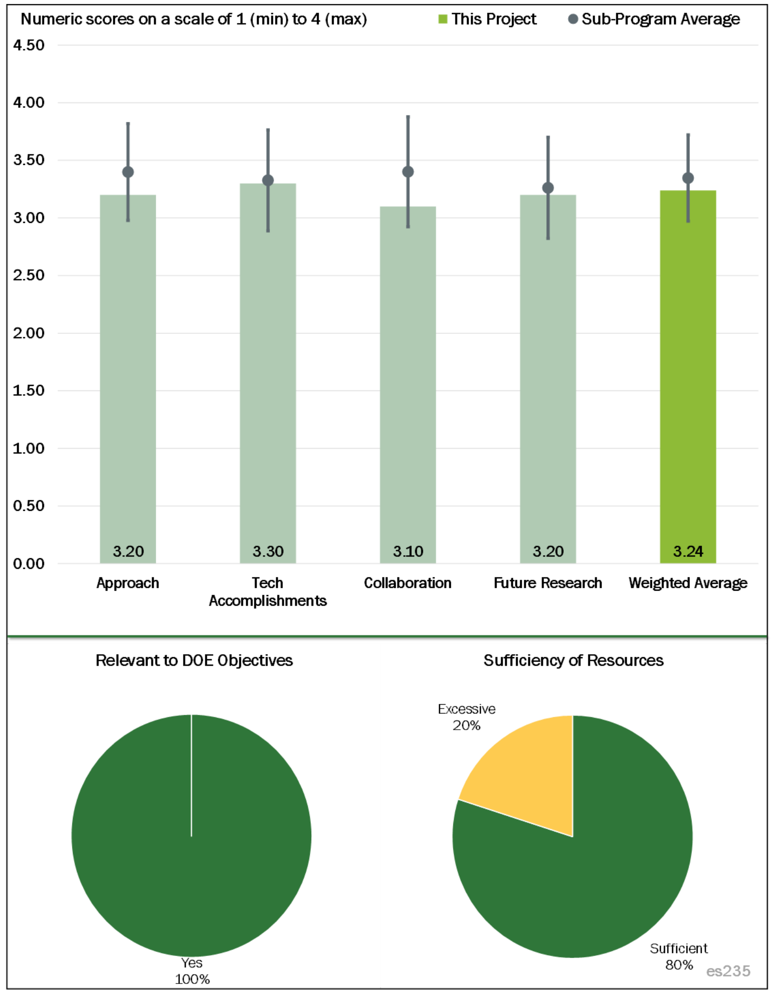

Figure 3-26 - Presentation Number: es235 Presentation Title: Characterization Studies of High-Capacity Composite Electrode Structures Principal Investigator: Michael Thackeray (Argonne National Laboratory)

Presenter

Jason Croy, Argonne National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer praised the approach taken as excellent. It proceeds in a logical manner. A wide array of characterization techniques, including XRD and neutron diffraction, X-ray absorption, emission and scattering, HRTEM, and Raman spectroscopy, will be used to gain a better understanding of the challenges confronting the next generation of electrode materials. Once issues are identified, modeling will be undertaken to investigate the structure-property relationships so that improved materials can be designed.

Reviewer 2:

The reviewer said that there is an excellent selection of characterization techniques and modeling in this project that should also be used to benchmark commercially available materials from ANL licensees, for example. It is also important to demonstrate reproducibility on the scale-up samples.

Reviewer 3:

The reviewer commented that what is critical here is not “challenging experimental problems” but “understanding material problems.”

Reviewer 4:

The reviewer said nice work, and liked that the work is focusing on more than just voltage fade, but other problems that need to be addressed as well. There is good work on scale up, but lots of work. It is an ambitious effort that seems to be going well.

Reviewer 5:

The reviewer described the objective here as gaining a fundamental understanding through modeling and detailed characterization of the next-generation, structurally-integrated, Li- and Mn-rich compositions that can provide high specific capacities at higher voltages compared to the conventional 4V cathode. Specific objectives are to improve the performance (including cyclic stability) of these composite structures by designing and synthesizing "stable" surfaces and three-component, LLS electrodes through characterization and modeling. A wide variety of characterization techniques, including XRD and neutron diffraction, X-ray absorption, HRTEM, and NMR spectroscopy, are being used in the characterization of these complex structures and complemented with modeling.

This project is addressing the technical barriers of energy density, cost, and abuse tolerance of the current cathode materials. Lithium-rich and Mn-rich LL oxides, Ni-rich NMC oxides, and LLS composites are the three classes of compounds for the next- generation cathodes and it is crucial that one gains a good understanding of these materials at the fundamental level, which the present project is addressing.

There is another project (ES049) with the same PI that overlaps significantly with this project *sans* modeling, which made the reviewer wonder why these two projects could not be combined into a single project. Overall, this project is well designed with new cathode structures, feasible, and adequately integrated with the other DOE efforts on the high capacity cathodes.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer stated that good progress has been made in designing and synthesizing LL cathodes with embedded spinel component of several new compositions (over 40) that are being evaluated for elemental-structural-electrochemical properties. LLS cathodes have been shown to provide approximately 215 mAh/g between 4.5-2.5V versus Li/Li^+. The reviewer remarked that early results on surface treatments (Al_2O_3, Li_3PO4, $Li_{2.9}Ni_{0.05}PO_4$, etc.) are promising, and the rate and energy are comparable to Ni-rich, NMC532 cathodes. These studies complement the synthesis efforts pursued in a parallel project (ES049) in order to understand the possibilities and electrochemical effects of incorporating Co-rich spinel, $Li_{2-x}[Co_{2-2y}Ni_y]O_4$ components. The reviewer explained that LT-$LiCo_{1-x}Ni_xO_2$ (approximately 400°C) consists primarily of lithiated-spinel, structurally integrated with a "defect" layered phase in which the cation distribution is intermediate between layered and spinel and the Ni substitution is limited, but, importantly, promotes the formation of spinel and suppresses the spinel-to-layered transition at elevated annealing temperatures.

This reviewer reported that simulations show that bulk oxygen lattice is stable up to about 50% Li removal from Li layers of Li_2MnO_3 component and Mn migration is correlated with O-O pairing. Surface stability is essentially zero, and any Li extraction leads to more instabilities, implying the need for surface stabilization.

The reviewer indicated that surface characterization studies are underway on these LLS structures coated with different coatings. A variety of materials seems to be beneficial, and $Li_{2.9}Ni_{0.05}PO_4$ shows the best high-rate performance. The reviewer noted that these LLS structures show promise for high capacities and good cyclic stabilities especially with surface coatings. They offer advantages in cost and abuse tolerance (but less so in the specific capacity) compared to the Ni-rich layered oxides. However, the incorporation of Co and Ni-based spinel may offset some of these advantages.

Overall, this reviewer opined that the technical accomplishments are significant and demonstrate the progress toward DOE goals.

Reviewer 2:
The reviewer observed that considerable progress was made last year. The team showed that particle processing is important to electrochemical performance. Various Mn-rich, LLS cathode materials were shown to yield high capacity and the rate is promising. Calculations and simulations show that surface protection is essential for Li- and Mn-rich cathodes.

Reviewer 3:
The reviewer commented that the goals of this project are not quantitative, but more focused on learning. To that end, the reviewer thought that there has been good progress. Other comments from the reviewer were that it would have been nice to see some full cell results and the characterization work was excellent.

Reviewer 4:
The reviewer remarked that very high quality data are presented but most of those are not immediately clear. Some small plots are not really visible. For example, in Slide 12, the reviewer wanted to know what those color indices are, whether only numbers are specified, and what the voltages are.

In the Li(oct) and Li(tet) argument, the reviewer posited that if Li(oct) is in an amorphous phase more favorably compared to Li(tet), then XRD peak ratio analysis becomes invalid. The reviewer wondered how such a possibility could be excluded. Extreme local information (e.g., HRTEM and XRD, although those are in very high qualities and good references), should not be directly correlated to the electrochemical performance data because performance data reflect the ensemble of the material in the electrode including amorphous phases and even impurities.

Coated materials show not only improved stability but also enhanced rate capability. The reviewer asked if there is any explanation so one can identify the material design direction.

Reviewer 5:
The reviewer had questions about the specific challenges of Li- and Mn-rich compositions and whether this system has a better chance for the commercial success versus Li-rich NMC materials.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer opined that excellent collaborations exist. These include various scientists from ANL, ORNL, Northwestern University, and PNNL. Each of the scientist bring unique expertise (e.g., NMR, XAS, and TEM) that will help the program tremendously.

Reviewer 2:
The reviewer remarked that collaboration looks good.

Reviewer 3:
The reviewer noted that there are good collaborations with several researchers from ANL and also with external DOE researchers in understanding these materials at the fundamental level and with the university researchers on modeling. It would be more appropriate and timely to collaborate closely with industry to establish the merit and relevance of these materials compared to NCA-based cathodes or Ni-rich cathodes, as is being planned.

Reviewer 4:
The reviewer asserted that there could have been broader collaborations; the project seems heavily ANL focused.

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.

Reviewer 1:
The reviewer found the proposed future efforts to be rational. Characterization of the materials stemming from project ES049 will continue in order to assess their value.

Reviewer 2:
The proposed future research is to continue the development of these LLS cathodes with new surface coatings to optimize specific capacity, operating voltage, rate, and cyclic stability. Future studies involve completing the characterization of 40+ new compositions that have been synthesized for specific elemental-structural-electrochemical properties and working to understand the possibilities and electrochemical effects of incorporating Co-rich spinel ($Li_{2-x}[Co_{2-2y}Ni_y]O_4$) components in the LLS composites.

Characterization of the robust surface structures with various surface coatings will be augmented with theory and simulation along with characterization of LLS electrodes harvested from full cells (versus graphite anodes) for ascertaining the efficacy of surface coatings on cyclic stability. It is also important to demonstrate the benefits of these LLS cathode materials with surface coatings in an industrial environment in comparison with the surface-treated NCA-based cathode to properly address the technical barriers in the VTO program.

Reviewer 3:
The reviewer expressed anticipation about the results for all 40 compositions and hoped this can be completed in the time remaining. The reviewer also wanted to see more detail about how much characterization and testing were being planned for the other compositions.

Reviewer 4:
The reviewer stated that it appears the effort does not go beyond that in ES049. The only difference is pursuing Mn-rich instead of Ni-rich material.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer pointed out that furthering the understanding of the structure-electrochemical property relationships and degradation mechanisms of promising cathode materials will contribute significantly to meeting the DOE near- to long-term goals of EV battery technologies.

Reviewer 2:
The reviewer observed that low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles. High specific energy cathode materials (at high discharge rates) with reduced cost and improved safety are required to address these shortcomings. The LLS composite cathodes with suitable surface coatings are promising to provide stable structures, with high capacities at high rates and as being addressed in this project. This project is thus highly relevant to the DOE goals.

Reviewer 3:
The reviewer commented that high energy density materials are required to achieve the overall DOE goals and this material is an important part of the DOE portfolio. Do not give up on it.

Reviewer 4:
The reviewer said likely.

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

Reviewer 1:
The reviewer asserted that resources appear more than sufficient.

Reviewer 2:
The reviewer stated that resources are consistent with the scope of the project.

Reviewer 3:
The reviewer affirmed that resources are sufficient in order to successfully complete the effort in a timely manner.

Reviewer 4:
The reviewer did not know what is planned for the remaining compositions but assumed it is streamlined from the detailed characterization work shown in this presentation. Otherwise, more resources might be required.

Presentation Number: es240
Presentation Title: High-Energy Anode Material Development for Lithium-Ion Batteries
Principal Investigator: Cary Hayner (Sinode Systems)

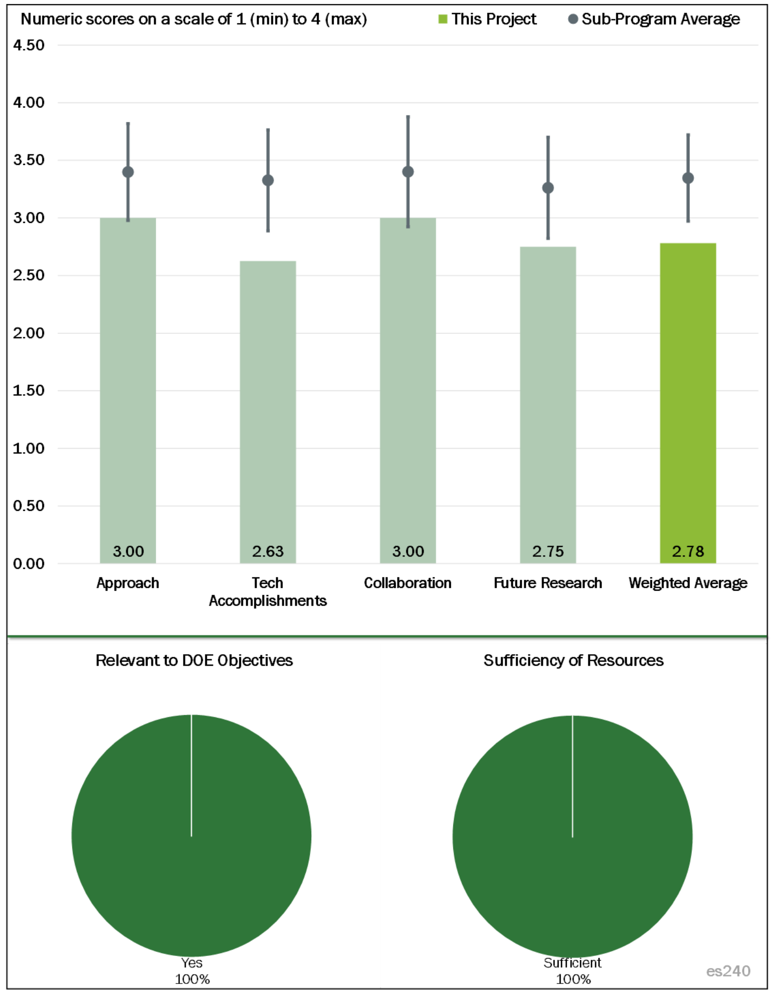

Figure 3-27 - Presentation Number: es240 Presentation Title: High-Energy Anode Material Development for Lithium-Ion Batteries Principal Investigator: Cary Hayner (Sinode Systems)

Presenter

Cary Hayner, Sinode Systems

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that the project is well designed and feasible.

Reviewer 2:

The reviewer described the objective of the project as developing high specific energy Li-ion cells utilizing a high-capacity SiC-based anode that can exceed DOE performance targets. The goals for this project are 200 Wh/kg for 1,000 cycles at the cell level when paired with commercial cathode materials and 750-1,500 mAh/g for 1,000 cycles for the anode. Another objective is to further optimize its manufacturability to meet commercially viable production protocols.

The corresponding deliverables were to demonstrate cycling performance of a 1 Ah SiNode anode coupled with a high energy cathode and submit a comprehensive report on current failure modes and a roadmap to reduce costs to meet DOE target.

The approach is to use SiNode's material, which is Si particles wrapped in a flexible, conductive graphene shell wherein the engineered void space accommodates Si expansion during lithiation. The micron-sized particles are customizable, and the company expects this design to be a drop-in replacement for existing anode materials. The projected anode capacity is 2,000 mAh/g, which has never been achieved experimentally before with any Si anode.

Interestingly, there is no mention of the reversible and irreversible capacities of this anode material. Also, the usual technical barriers for the Si-based anodes are poor cycle life due to volume expansion and also low coulombic efficiency in the first couple of cycles.

Surface coatings were used here to improve the cyclic stability. The use of Si anodes can result in some gains in specific energy and energy density, but only after proper pre-lithiation, which is not explicitly mentioned or addressed here.

Overall, the project is well designed, integrated with other efforts, and consistent with the project and DOE goals.

Reviewer 3:
The reviewer noted that the PI presents a plan to get to a Si-graphene composite material drop-in replacement for graphite in transportation Li-ion cells. This is obviously not the first company developing a Si-graphene composite material. The plan is rather general with not a lot of details. The reviewer found it interesting that the company does not plan to scale up the material past a certain level; rather, they will license the technology if successful.

Reviewer 4:
The reviewer stated that the team is using graphene encapsulation, which is a fine idea. However, there are other technologies that are much farther along, and it is not clear that this technique has a strong chance of doing better than those technologies.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer commented that reasonably good progress has been made in scaling the SiNode synthesis several orders of magnitude without performance degradation. Optimized material formulations and scalable surface treatment (additives) have resulted in improvements in cycle life (both columbic efficiency and specific capacity are claimed to be improved) and suitable external suppliers were identified for reducing material costs by more than 10 times to meet the DOE cost target. Further, an improved thermal processing procedure has been shown to increase cycle life by more than 67% and improve irreversible capacity and coulombic efficiency. Thus, the modified graphene material with surface stabilization offers attractive performance and inexpensive cost compared to the control material.

In situ TEM observations confirmed that the graphene shell successfully wraps Si particles during lithiation while the void spaces accommodate Si expansion during lithiation and buffered overall particle expansion. Details are not presented here about the specific capacities and columbic efficiency (irreversible capacity) that would allow an assessment of the capability of these materials.

Even with all these improvements, the performance is well short of the DOE goals of 750-1,500 mAh/g for 1,000 cycles, underlining the challenges with the Si-based anodes. Overall, the progress is fair and is consistent with the scheduled milestones and DOE goals.

Reviewer 2:
It was clear to the reviewer that the end performance target of 750-1,500 mAh/g for the anode has not been reached. In the presentation, cycling performance data up to only 140 cycles were presented and no capacity data were reported.

The 10,000X scale-up of production process seems to have been achieved without performance degradation.

The reviewer gave a 2.5 rating because SiNode's efforts (adding additives and coating) improved to a certain degree the performance of SiC anode.

Reviewer 3:
The PI has made progress, but it is also clear the material needs quite a bit more development. As far as the reviewer can tell, all the data pertain to half-cells and are plotted as capacity retention, rather than specific capacity, with no current efficiency data. This tends to show the material in the best light, but it is not very informative.

Reviewer 4:
The reviewer found the present status to be not very good: fewer than 200 cycles and SEI issues not being addressed. A maximum production rate of 180 g/day is still very low. All of these accomplishments are far behind other companies, such as Amprius and Sila Nano.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer pointed out that SiNode collaborated with Northwestern University and the University of Illinois at Chicago (UIC)

Reviewer 2:
The reviewer stated that there were collaborations with university partners (Northwestern and UIC) in the characterization of materials and with Merck for the material supply.

Reviewer 3:
The reviewer noted that there are a few collaborations.

Reviewer 4:
The reviewer stated that they are funded by USABC, which implies connection to the auto companies.

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.

Reviewer 1:
The reviewer pointed out that the project ended at the end of July 2016.

Reviewer 2:
The reviewer asserted that the project ended in July 2016, but there are still a few challenges remaining. SiNode needs to continue development to demonstrate longer cycle life (greater than 500 cycles) prototype cells and high energy required for commercialization. The supply chain, active material formulation, and scale-up manufacturing to achieve long-term cost targets need to be explored, and comprehensive safety testing on prototype cells required to determine characteristics has to be performed.

Reviewer 3:
The reviewer noted that there is no future work because the project is over.

Reviewer 4:
The reviewer commented that the team knows what needs to be done, but did not see how the team plans to accomplish those goals.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer observed that low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles. High capacity anode materials are required to improve the specific energy of Li-ion cells. Si anodes have the potential to offer twice the capacity of graphitic anodes, and SiNode has developed a fairly robust Si anode based on graphene. These high-capacity anodes are to be paired with high-capacity commercial cathodes to provide high specific energies and energy densities for Li-ion cells with lower costs.

Reviewer 2:
The reviewer stated that the project aimed at developing SiC anodes for LIBs with extended cyclability, which is important for EVs.

Reviewer 3:
The reviewer pronounced the work to be relevant.

Reviewer 4:
The reviewer said okay.

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

Reviewer 1:
The reviewer found the resources to be adequate.

Reviewer 2:
The reviewer stated that the funding is sufficient.

Reviewer 3:
The reviewer said resources are okay.

Reviewer 4:
The reviewer had no comments.

Presentation Number: es241
Presentation Title: Advanced High-Performance Batteries for Electric Vehicle (EV) Applications
Principal Investigator: Ionel Stefan (Amprius)

Presenter

Ionel Stefan, Amprius

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

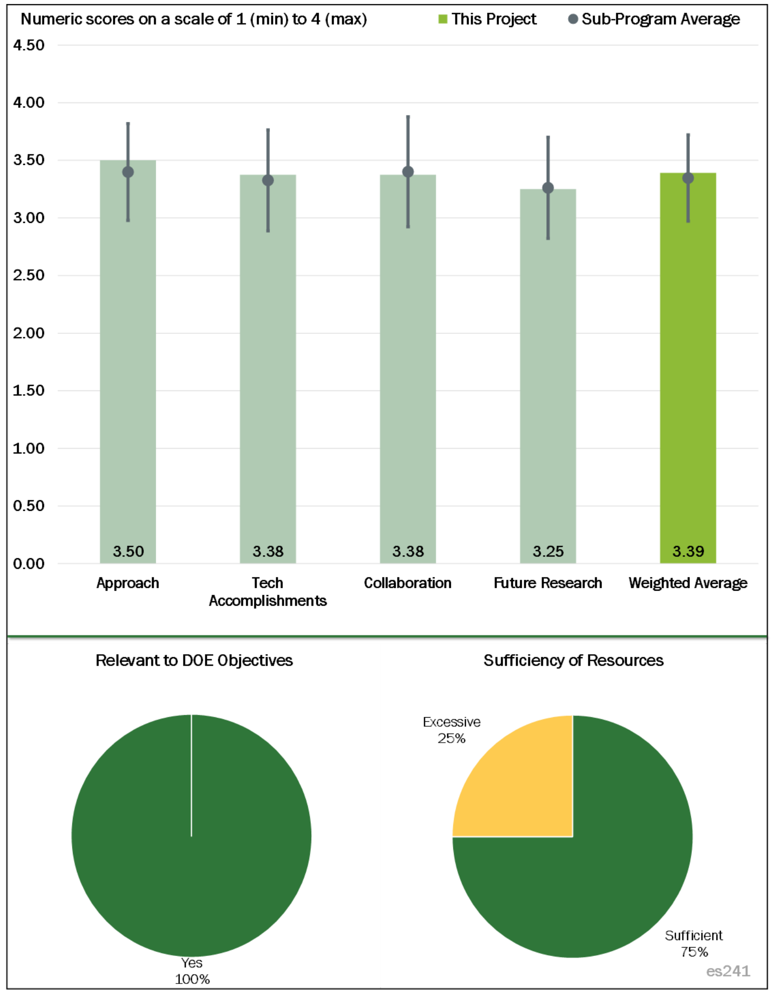

Figure 3-28 - Presentation Number: es241 Presentation Title: Advanced High-Performance Batteries for Electric Vehicle (EV) Applications Principal Investigator: Ionel Stefan (Amprius)

Reviewer 1:

The reviewer pronounced the project as being well designed and feasible. The Si nanowire anode is a promising approach to develop high-performance batteries.

Reviewer 2:

The reviewer pointed out that the project has highly original approaches to providing full cells with high energy density.

Reviewer 3:

The reviewer observed that the objective of the project is to develop high specific energy Li-ion cells utilizing Amprius Si nanowire anodes for EV batteries. Specific objectives are to design and fabricate Si nanowire anodes matched with advanced (high capacity and high energy density) cathodes and state-of-the-art cell components. Additional work covers design, fabrication, testing, and delivery of 2 Ah, 10 Ah, and 40 Ah Li-ion cells with Si nanowire anodes that meet the USABC 2020 goals of 350 Wh/kg and 750Wh/l at end of life (EOL), 2:1 power-to-energy ratio, and 1,000 dynamic stress test (DST) cycle life.

The technical barriers that will be addressed are to reduce the mass and volume of the anode for higher energy density and specific energy, reduce cost, and improve the cycle life by optimizing the nanowire structure. The use of a Si anode can result in some gains in specific energy and energy density, especially after proper pre-lithiation. However, with the Si anode, even with nanowires, the cycle life would be a considerable challenge especially for EV applications, though some decent cycle life has been reported here.

The specific approach involves matching Si nanowire anodes with advanced (high capacity and high energy density) cathodes and state-of-the-art cell components, developing anode and other cell components in a 2 Ah cell form factor and later scale it up to an intermediate 10 Ah cell and modify to 40 Ah cells for performance demonstration.

Overall, the project is well designed and integrated with other efforts and consistent with the project and DOE goals.

Reviewer 4:

The reviewer has followed this project from the beginning with great interest. The unique anode design combined with industrial connections makes for a very real world test of the technology. Amprius does not seem to be able to calculate the percentage of completion accurately, but they have done a lot of other, more important things well. They are focusing on technology development, but should have a better plan to convince the reviewer and others that this technology can be made affordably.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer commented that Amprius has already achieved the milestone of 800 Wh/l, 380 Wh/kg, and 850 cycles in 2 Ah cell and 10 Ah cells with similar performance. It is very likely that they will reach their remaining goals at the end of the project, which are to develop, test, and deliver 2 Ah, 10 Ah, and 40 Ah Li-ion cells with Si nanowire anodes that meet the USABC 2020 goals.

Reviewer 2:

The reviewer mentioned that good progress has been made in developing the first-of-its-kind pilot line tool for roll-to-roll production of double-sided, rooted Si nanowire anodes with high Si content (100%), high loading (2-3 mg/cm^2), and matching the Si nanowire anode with high-capacity NMC cathodes. High capacity cathodes of high loadings, high specific energy, and densities have been demonstrated in 2-3 Ah cells, with the performance exceeding the DOE targets of 350 Wh/kg and 750 Wh/l. Further, the cycle is reasonable with more than 500 cycles for the NMC cathode and 300 cycles with LCO cathodes operating at high charge voltages of 4.35V. Operating at these charge voltages may aggravate the safety issues with the LCO cathode, however. With the NMC cathode, the voltage profile will be more sloping to add to the relatively sloping voltage profile of Si.

About 30 Si nanowire-NMC cells have been delivered to INL and SNL for performance and safety evaluation. It would more appropriate to show the data generated at INL and SNL as part of this review. Finally, a design was developed for larger (10 Ah) Si nanowire and NCM cells with specific energy of 340 Wh/kg and 850 Wh/l. High cathode loadings contribute to higher specific energy, no doubt, but only at the cost of cycle life. It is important to understand the interplay among cathode loadings, energy densities, and cycle life.

Overall, the progress is good and is consistent with the scheduled milestones and DOE goals.

Reviewer 3:

The reviewer remarked that they seem to be making steady progress on more than one front. It is good to see they are focusing more on NMC systems. Last year they touted 500 cycles, but it is not clear that they have increased on that value very much.

Reviewer 4:

The reviewer stated that they have overcome challenges in designing tabs for a 10 Ah cell. They have recently improved the energy density by about 10%, both volumetric and gravimetric and are getting 337 Wh/kg now. They are up to about 550 cycles with NMC550. A big challenge is the poor calendar life.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed that Amprius has a long list of collaborators including universities and industrial companies.

Reviewer 2:
The reviewer said that Amprius has collaborations with other companies where necessary.

Reviewer 3:
The reviewer observed that they have had to develop a number of collaborations to push the technology forward.

Reviewer 4:
The reviewer pointed out that Amprius is the only project team member. However, there are multiple industrial and university partners for the development of cathode and electrolyte to go with the Si nanowire anodes.

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.

Reviewer 1:
The reviewer discussed what future studies will involve: the continuation of cell optimization to increase specific energy, cycle life, and calendar life using the design of the experiment methodology for electrolyte studies, completion of testing the 10 Ah cells with INL and SNL to map out the performance gap table, and the development of the design for 40 Ah cells by iterating the cell assembly, evaluating performance, and fabrication and delivery of the cells. The future work planned is logical with appropriate decision points in the materials selection and cell fabrication processes. These future studies are consistent with the DOE goals

Reviewer 2:
The reviewer asserted that Amprius has well-defined plans for future works, such as further cycle life and high-temperature stability improvements by optimization of electrolyte formulation.

Reviewer 3:
The reviewer commented that they seem to have an excellent plan for their performance metrics. Again, it would also be interesting to see some consideration of cost.

Reviewer 4:
The reviewer expressed a lot of confidence that they will be able to fabricate 40 Ah cells, but did not see how they will solve their calendar life problem.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer commented that low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles. High capacity anode materials are required to improve the specific energy of Li-ion cells. Si anodes have the potential to offer twice the capacity of graphitic anodes, and Amprius has developed a fairly robust Si anode based on Si nanowires. These high-capacity anodes are to be paired up with high-capacity cathodes in suitable electrolytes so that prototype cells (10-40 Ah) can be fabricated to validate the benefits of the Si nanowire and NMC cells. High gravimetric and volumetric demonstrated in these cells will make the EV batteries lighter, more compact, and may be even lower cost.

Reviewer 2:

The reviewer observed that the more than 1,000 cycle life of LIBs is one of the central problems to be solved for their application in EVs. The project also works on improvements in energy density, high temperature stability, and calendar life of LIBs.

Reviewer 3:

The reviewer stated that the project is relevant.

Reviewer 4:

The reviewer said okay.

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

Reviewer 1:

Based on the demonstrated works and the wide collaborations, the reviewer believes that Amprius has sufficient resource to achieve the stated milestones on time.

Reviewer 2:

The reviewer stated that resources are sufficient.

Reviewer 3:

The reviewer said resources are okay.

Reviewer 4:

The reviewer commented that the resources seem to be excessive compared to FY 2016 though the scope is similar (except the size of the cell deliverables).

Presentation Number: es247
Presentation Title: High-Energy Lithium Batteries for Electric Vehicles
Principal Investigator: Herman Lopez (Envia Systems)

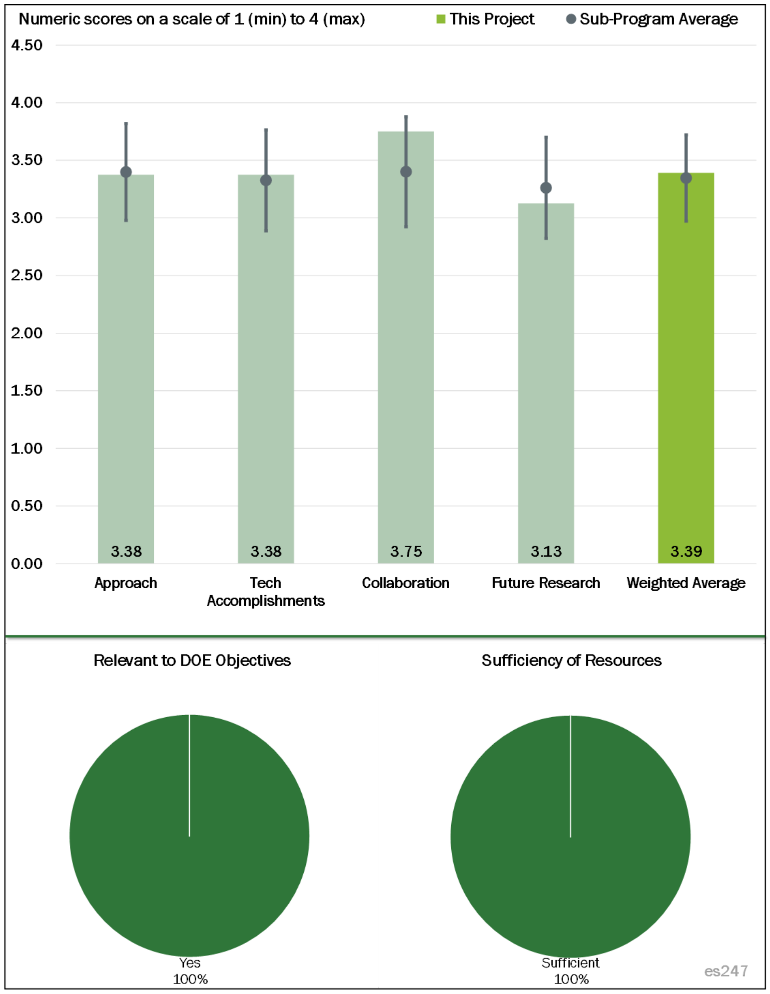

Figure 3-29 - Presentation Number: es247 Presentation Title: High Energy Lithium Batteries for Electric Vehicles Principal Investigator: Herman Lopez (Envia Systems)

Presenter

Herman Lopez, Envia Systems

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

This reviewer stated that Envia's project, centered in the optimization of the pre-lithiation process of silicon oxide (SiO_x) anode, is well-designed and feasible, and a promising approach to develop high-performance batteries.

Reviewer 2:

The reviewer confirmed the objective here is to develop high-capacity cathode and anode materials, screen commercial electrolytes and separators, optimize pre-lithiation process and integrate the materials and processes into high-capacity pouch cells that meet the USABC EV battery goals, i.e., 300 Watt-hour per kg (Wh/kg), 750 Watt-hour per liter (Wh/l) and cycle life 1,000 DST cycles. The challenges here are related to the poor cycle life of (n-rich or Ni-rich cathodes and S) anodes and to identify a viable pre-lithiation process and to develop cell designs that meet the safety and cost targets. To achieve these performance characteristics, the reviewer stated the approach adopted was to collaborate with multiple partners, especially on the Si anodes, separators and electrolytes. Based on these materials, the reviewer commented proprietary electrode processes and cell designs are being developed to demonstrate the performance targets in 1 to 20 Ah cells. Eventually, these cells will be sent to the DOE national laboratories (INL, SNL, and NREL) for an independent performance verification and validation. Overall this reviewer summarized that the project is well designed, integrated with other efforts and consistent with the DOE's goals.

Reviewer 3:

This reviewer confirmed there was a clear division of labor among many companies for what needs to be done.

Reviewer 4:

The reviewer noted this project is certainly challenging with many problems to overcome. The PI seems to understand the problems and has a plan to attack them. This reviewer found the blending strategy for the cathode interesting, hoping to get the best of both materials. Although in the end, the reviewer opined the anode may present the greatest challenge.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer acknowledged Envia has achieved more than 700 cycles with 80% retention from 20 Ah cells using high SiO_x containing anodes, and stated that this meets the USABC 2020 goals. This reviewer expects that the project team will improve the performance of their cells to meet the USABC EV specs by the end of the project.

Reviewer 2:

The reviewer noted the project seems the have made steady progress. The 700-plus cycle life is particularly impressive. The use of SiO_x in the anode forces one to consider pre-lithiation, which this reviewer stated continues to be a challenge.

Reviewer 3:

This reviewer confirmed 700 cycles at 300 Wh/kg is very good. Pre-lithiation of SiO_x could be a serious problem in terms of cost; however, the reviewer noted that the project is collaborating with a company to address this.

Reviewer 4:

The reviewer said good progress had been made with various cell components and cell designs: A cycle life of 800 cycles was realized in 21 Ah, (270 Wh/kg) pouch cells with nickel-rich nickel manganese cobalt oxide (NMC) cathode and Si anode (less than 50%) with suitable pre-lithiation. Proprietary Si-based anodes were developed by using commercially available SiO_x materials and applying proprietary electrode formulation, processing, and coating methodology. This reviewer noted both Mn-rich and Ni-rich cathodes will provide the high energy densities (350 Wh/kg and 750 Wh/L when combined with the Si anode, and also meet the safety and cost requirements. Large-scale roll-to-roll pre-lithiation pilot line was completed the reviewer remarked and is currently being used to pre-lithiate promising anode formulations for 20 Ah cells. The reviewer pointed out there are no data here (on the anode irreversible capacity or coulombic efficiency during formation) to quantify the benefit of this pre-lithiation. Prototype cells were fabricated (11-20 Ah) that showed consistent cell performance (260-280 Wh/kg) and physical specifications, and also meet the EOL USABC EV peak specific Regeneration and Discharge power requirements after reference performance test (RPT) 1 (post 30°C DST cycling). This reviewer mentioned the next generation of the cells are expected to provide higher specific energy of 300 Wh/kg and 1,000 cycles. As impressive as these performance numbers are, the reviewer observed the results are not much more impressive than the recent high-energy commercial 18650 cells that provide 265 Wh/kg and 800 Wh/l with graphitic anodes at the cell level. Proper cost analysis needs to be made to assess from the pre-lithiation and the associated electrode handling needs versus its benefits. Overall progress is good the reviewer summarized and is consistent with the DOE's goals.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

This reviewer said the project team is doing an excellent job collaborating with the right people.

Reviewer 2:

This reviewer commented there are excellent collaborations with several researchers from different organizations, specialized in different components and manufacturing processes.

Reviewer 3:
The reviewer stated Slide 5 shows a well-organized collaboration among industrial and national laboratory partners.

Reviewer 4:
The reviewer asserted the project has extensive collaboration in many areas.

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.

Reviewer 1:
The reviewer noted the project is nearing completion this year. The remaining activities are: to complete Cell Build #2 and deliver cells to the national laboratories for their assessment; downselect best pre-lithiation process to be used in final cell build; and complete Cell Build #3 development and freeze cell design for final program cell deliverable. This reviewer stated the future work planned is consistent with the project objectives and deliverables.

Reviewer 2:
This reviewer noted Envia listed detailed steps for future works.

Reviewer 3:
This reviewer concluded directions are clear, but pathway to success is unclear.

Reviewer 4:
The reviewer warned as this project is nearing completion, the future plans are somewhat limited. The reviewer thought the PI will be able to look back and feel good about the progress. It will be interesting for this reviewer to see the independent testing of the technology.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer observed low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles. High capacity cathode and anode materials are required to improve the specific energy of Li-ion cells. This reviewer noted blends of Ni/Mn-rich cathodes and Si composite anodes with proprietary pre-lithiation strategy are promising both from an energy and cost perspective. These high-performance and low-cost materials and processes are being addressed in this project the reviewer concluded.

Reviewer 2:
The reviewer affirmed the project is good.

Reviewer 3:
This reviewer stated the project is relevant.

Reviewer 4:
This reviewer commented the major objective of Envia's project is to develop high-energy Li batteries to meet the USABC EV specs.

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

Reviewer 1:
Based on the demonstrated work and the wide collaboration, the reviewer believes that Envia Systems has sufficient resource to achieve the stated milestones in time.

Reviewer 2:
The reviewer acknowledged the resources are adequate based on the scope of the effort that ranges from material and process development to the fabrication of high-capacity prototype cells for performance demonstration.

Reviewer 3:
The reviewer asserted the resources are sufficient.

Reviewer 4:
The reviewer stated the resources for the project were okay.

Presentation Number: es252
Presentation Title: Enabling High-Energy/Voltage Lithium-Ion Cells: Electrolytes and Additives
Principal Investigator: Dennis Dees (Argonne National Laboratory)

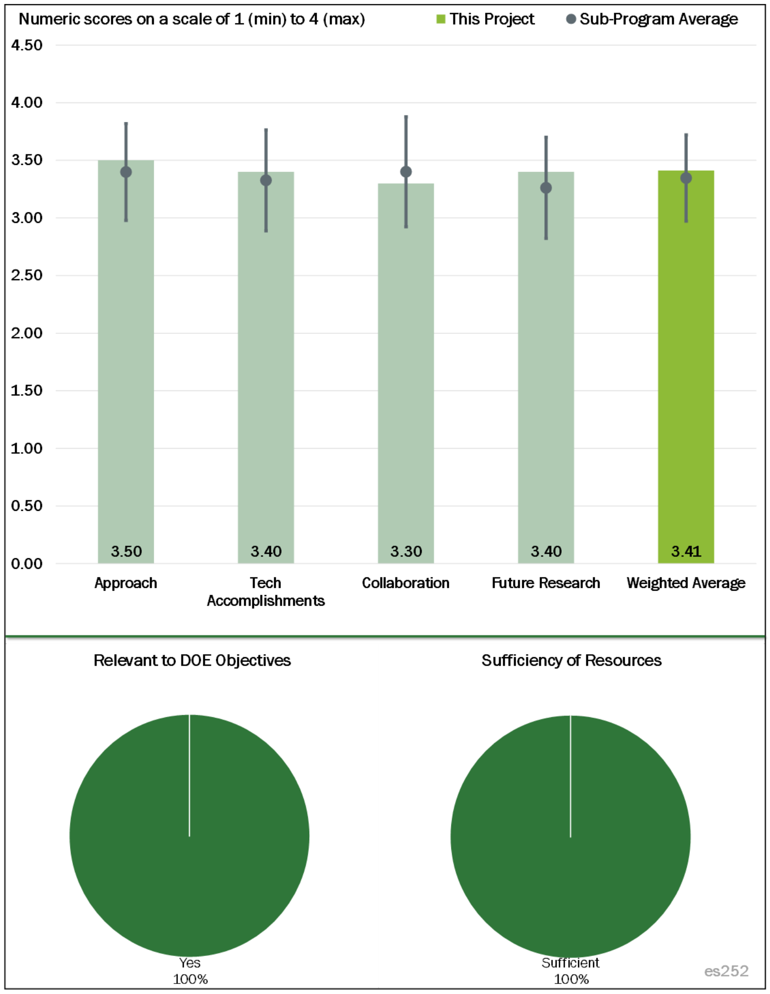

Figure 3-30 – Presentation Number: es252 Presentation Title: Enabling High-Energy/Voltage Lithium-Ion Cells: Electrolytes and Additives Principal Investigator: Dennis Dees (Argonne National Laboratory)

Presenter

Daniel Abraham, Argonne National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer asserted the combined computational and experimental approach is very well designed and very effect to study electrolyte stability and additives.

Reviewer 2:

This reviewer observed this project's goal is to develop electrolytes and additives for high-energy/voltage Li-ion cells. It has well-designed and feasible experimental plan in the proposed work and been integrated well with the other teams' efforts. The reviewer affirmed the project took good advantage of ANL's CAMP facility to prepare standard electrodes for various tests. The capacity degradation mechanism is studied from full cell point of view and well correlated to the experimental results. The reviewer commented standard protocols are used to evaluate the effect of electrolytes/additives.

Reviewer 3:

The reviewer stated the effect of electrolyte additives has been studied using a mini combinatorial approach. The studies have used energy figure of merit and power figure of merit as two criteria to compare the effect of additives, and electrolyte with no additives are reasonably used as baseline. In addition to the electrochemical tests, the reviewer noted nuclear magnetic resonance (NMR) and XPS studies are used to explain the mechanism of interactions between electrode surface and electrolyte with difference additives. Electrochemical impedance tests have also provided important insights regarding the reactions on the surface of positive and negative electrodes.

Reviewer 4:

The reviewer recounted the project approach identifies the issue that will be addressed; outlines what will be done to try to mitigate the causes of the issue; and highlights the need to be able to model what happens and report the results. The need for support by a number of other agencies was also noted.

Reviewer 5:

The reviewer concluded the approach is feasible to understand the degradation mechanism of NMC532/graphite electrode. However, the industry is now using NMC622 and exploring NMC811, thus the baseline material could be out of date. The reviewer stated the goal of this project is to explore new electrolyte and electrolyte additives using EC:EMC and baseline electrolyte to understand the interaction between EC and different electrolyte additives. In the future plan, EC free will be used. The question this reviewer had is how much learning from baseline can be applied to total new electrolyte system with new electrolyte additives.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This reviewer remarked progress showed significant improvement over the baseline performance. The presentation clearly spelled out the reasons for the improvement by reviewing the strengths/weaknesses of electrolyte additives with respect to electrodes and power and energy figure of merit. The reviewer noted the project also developed tests for specific electrolyte evaluation.

Reviewer 2:

The reviewer expressed the outcome of the project will help design liquid electrolyte compounds that will enhance the calendar- and cycle- life of high-energy LIBs. The accomplishments of the project are within the mainstream of electrolyte studies, and the part of the work that tries to propose possible mechanisms for surface reactions is more novel in the opinion of this reviewer.

Reviewer 3:

This reviewer affirmed this work made great progress in understanding the effects of electrolyte additives on cell impedance. It can be improved by using surface techniques to better understand the role of these additives.

Reviewer 4:

This reviewer asserted good progress toward overall project and DOE goals was made. Performance, especially the power performance, improvement has been demonstrated after screening various additives and their combinations. The reviewer pointed out the fundamental mechanism underneath the additives is also explored with some new insights provided to the community. The PI has discovered that the content of transition metal at the negative electrode increases with increasing upper cutoff voltage, which traps $Li+$ ions. To this reviewer it is not clear why the cell variation is still large when using the standard protocols in NMC532/graphite (Gr) coin cell (3-4.4 V) testing. At high voltages, aluminum (Al)-clad is suggested to be used to passivate the cell pans at high voltages. The electrochemical window of each additive needs to be considered which this reviewer noted is missing in the table. If a switch is made from coin cells to pouch cells, this reviewer wondered whether the same optimized recipe will work the best or whether a new round of screening will be necessary. The function of trivinylcyclotriboroxane (tVCBO) is not clear to the reviewer but it could provide some guidance in the further development of additives. When evaluating electrolyte/additives, the reviewer noted Coulumbic efficiency is an important indicator that needs to be reported which is missing in this project.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

This reviewer praised the excellent collaboration with multiple individual and facility contributors. The strengths of each was maximized for best possible results.

Reviewer 2:

The reviewer affirmed the work is done mainly at ANL, and there is a reasonable degree of collaboration between various divisions/groups within the lab.

Reviewer 3:
This reviewer commented he PI has collaboration with CAMP and post-test facilities at ANL.

Reviewer 4:
The reviewer observed this project works closely with CAMP at ANL. It is not very clear to this reviewer what the other national laboratories' contributions were to this project.

Reviewer 5:
This reviewer asserted the baseline electrolyte has been widely studied. Some of the collaborators are developing high-voltage electrolytes. The reviewer stated the project team can have more interaction with those experts and test the high voltage electrolytes.

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.

Reviewer 1:
This reviewer commented the results show that Li-ion cells with certain combinations of electrolyte additives exhibit improved performance. Future plans of the project are mainly focused on obtaining more insights into the mechanism and function of the reactions in these promising systems, and the reviewer noted a list of activities in line with this goal are proposed.

Reviewer 2:
This reviewer confirmed the project team identified potential areas for electrolyte improvements and what needs to be understood to make those improvements. One area missing as observed by this reviewer is comparing the cost associated with these electrolyte additives and their effects. The reviewer also, would like to have seen effects of varying the percentage of additives in the matrix.

Reviewer 3:
This reviewer stated that in order to better understand the effects of electrolyte additives on cell impedance, the PIs can leverage great resources of surface science expertise and instruments at national laboratories to better understand the role of these additives.

Reviewer 4:
The reviewer said the proposed future work has a detailed plan which is in the right direction. This reviewer suggested that Coulombic efficiency, especially for the full cells, needs to be included for evaluating various electrolytes and additives. The storage life of the cells in the presence of the additives at room and high temperature effects need to be considered. If the conclusion on the TM content at high cutoff voltage is correct, the reviewer pointed out corresponding strategies need to be proposed to mitigate the dissolution of TM from electrolyte or additive point of view. This reviewer pondered whether the EC-free system in the future work is consistent with the finding on TM dissolution. Electrochemical modeling that can quickly screen different electrolytes and additives is needed remarked the reviewer.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated this project supports the overall DOE objectives with respect to petroleum displacement. The project is seeking to significantly reduce a key failure mechanism for the LIB system—energy fade. The reviewer observed the project team is doing this via better understanding of what electrolyte additives impact that characteristic and which ones decrease that fade. Reducing that fade improves the chances of consumers adopting this technology for vehicle use.

Reviewer 2:
The goal of the project is to enhance the cycling performance of high-energy batteries which the reviewer noted thereby facilitates the transition from a fossil fuel based economy to one that may be driven by a mixture of fuels.

Reviewer 3:
This reviewer asserted this project supports the overall DOE objectives. Electrolytes and additives are the main roadblocks for developing high-energy/voltage battery systems.

Reviewer 4:
This reviewer mentioned electrolyte additives are used to improve the battery performance. A better understanding of the role of electrolyte additives, can significantly advance battery electrolyte development and help accelerate the EV adoption.

Reviewer 5:
The reviewer pointed out understanding the failure of the electrode and electrolyte is critical to further optimize the future battery system.

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

Reviewer 1:
The reviewer expressed this work needs funding at this level to address this issue.

Reviewer 2:
This reviewer concluded the resources are sufficient for the project to achieve the stated milestones in a timely fashion.

Reviewer 3:
This reviewer asserted ANL has all the required facilities to conduct the proposed research.

Reviewer 4:
This reviewer observed the team of the project has access to sufficient resources including Advanced Photon Source (APS) user facilities. The project is in the middle of its third year and 65% of the project is completed.

Presentation Number: es253
Presentation Title: Enabling High-Energy/Voltage Lithium-Ion Cells: Theory and Modeling
Principal Investigator: Dennis Dees (Argonne National Laboratory)

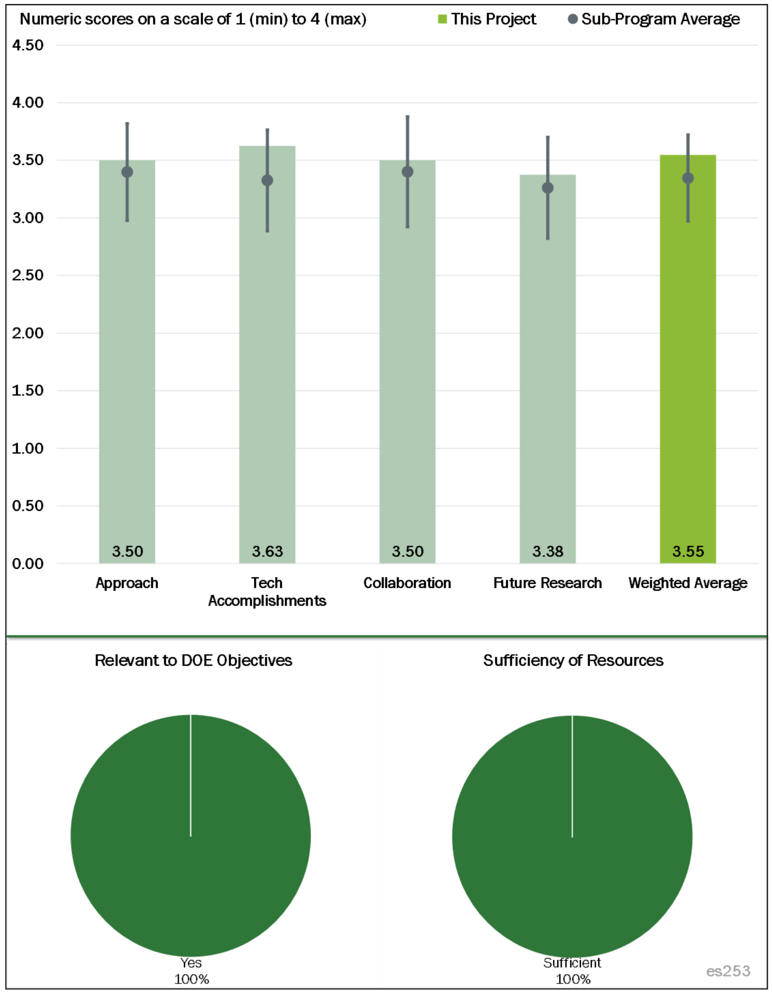

Figure 3-31 - Presentation Number: es253 Presentation Title: Enabling High-Energy/Voltage Lithium-Ion Cells: Theory and Modeling Principal Investigator: Dennis Dees (Argonne National Laboratory)

Presenter
Hakim Iddir, Argonne National Laboratory

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer stated the approach to perform first-principles DFT at the GGA+U and the hybrid functional levels is very helpful to understand bulk and surface structures, processes at surfaces and interfaces, and electrolyte-surface interactions.

Reviewer 2:
This reviewer praised the approach as excellent. Layered NMC are promising cathode materials that are intrinsically capable of meeting DOE goals. Unfortunately, surface degradation occurs that reduces the battery lifetime this reviewer acknowledged. The reviewer affirmed that this effort will use DFT to gain a better understanding on the atomic-scale processes governing battery degradation.

Reviewer 3:
This reviewer noted the project uses atomistic modeling to provide detailed understanding of NMC cathode both in bulk (lattice) and on the surface. The project uses both GGA-U and hybrid functional levels. The reviewer pointed out the modeling efforts are combined with experimental studies. There is a good agreement between the calculated surface energy of facets and the experimental findings regarding growth of NMC single crystals. The reviewer asserted valuable information on the formation of vacancies and transition metal cation segregation on the surface are presented. The obtained models are used to understand the interactions between cathode surface and electrolyte/additives and the reviewer concluded the results are consistent with the experimental findings and surface analysis.

Reviewer 4:
The reviewer observed that the approach identifies the issue that is being considered and how this project supports a broader project. This project objective is to handle the modeling portion of a larger project.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer praised this work for achieving very impressive milestones.

Reviewer 2:
This reviewer confirmed that significant progress was made this past year. One major contribution was the development of a model that can predict the surface structure, relative stability and particle shapes for NMC based cathode materials.

Reviewer 3:
This reviewer asserted the computational work in this project has provided valuable insights into the interaction of cathode surface with electrolyte and electrolyte additives, and that the outcome and predictions are consistent with the experimental findings. The project has had a significant progress in one year the reviewer observed, and the findings can be used as a predictive tool to improve high-energy LIBs.

Reviewer 4:
This reviewer concluded significant progress was made relative to stated objectives. An appropriate model for the Li-ion NMC cathode surface material was built as well as a model of the interaction of the electrolyte with the cathode. Other surface interactions were also modelled the reviewer noted. Bulk modelling was not clearly addressed this reviewer said, but was highlighted as an objective.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer said excellent collaboration with other teams was evident and needed. The strength(s) of each collaborator was maximized.

Reviewer 2:
The reviewer expressed this is a strong collaborative effort between four national laboratories (ORNL, NREL, LBNL, and ANL).

Reviewer 3:
The reviewer observed there were collaborations between various DOE national laboratories (samples obtained from LBNL) and modeling and experimental groups within ANL.

Reviewer 4:
The reviewer pointed out this work can be improved by providing more experimental support for the computational 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.

Reviewer 1:
The reviewer pointed out that the effort is scheduled to end next year. The concluding tasks to continue the modeling efforts and to investigate the electrolyte-additive/NMC surface interactions are good. This reviewer noted the results are expected to continue to give important insights into design criteria of high-performing cathode materials.

Reviewer 2:

The reviewer pointed out that the future work is presented relatively generally, and mainly as a continuation of the tasks performed so far. In most presentations the reviewer observed, the presenters had the concern of future funding and were skeptical about detailing their future work.

Reviewer 3:

This reviewer commented that the proposed future work supports the overall project as it provides modelling to help direct the work and then allows for modelling refinement based on test results. The reviewer stated that ideally, a clear Bulk Modelling effort should be called out in the future plans.

Reviewer 4:

This reviewer noted that the future plan should include more interaction with experiment team to confirm the computational results.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer said this portion of the larger project supports the overall DOE objectives with respect to petroleum displacement. This specific project handles the modelling that is needed to make the improvements to the energy component of the battery system.

Reviewer 2:

The reviewer affirmed the project's effort is aligned with the objective of petroleum displacement.

Reviewer 3:

The reviewer expressed the project provides knowledge on the cathode surface reactions that is believed to be the main origin for the degradation of LIBs, and thus will contribute to the enhancement of energy storage.

Reviewer 4:

The reviewer acknowledged that the project is very helpful in order to understand electrode bulk and surface structures, processes at surfaces and interfaces, and electrolyte-surface interactions to address the problems associated with "enabling" high-energy Li-ion cells.

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

Reviewer 1:

The reviewer concluded the funding level of this project meets the need of the overall project.

Reviewer 2:

This reviewer asserted the resources are sufficient for the project to achieve the stated milestones in a timely fashion.

Reviewer 3:

The reviewer affirmed the project team has access to sufficient resources and collaborations in order to perform the proposed tasks.

Reviewer 4:

This person said the project team has made significant progress with the resources they have received to date and there is no reason to assume that this will change in the future.

Presentation Number: es254
Presentation Title: Enabling High-Energy/Voltage Lithium-Ion Cells: Materials Characterization
Principal Investigator: Dennis Dees (Argonne National Laboratory)

Presenter
John Vaughey, Argonne National Laboratory

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

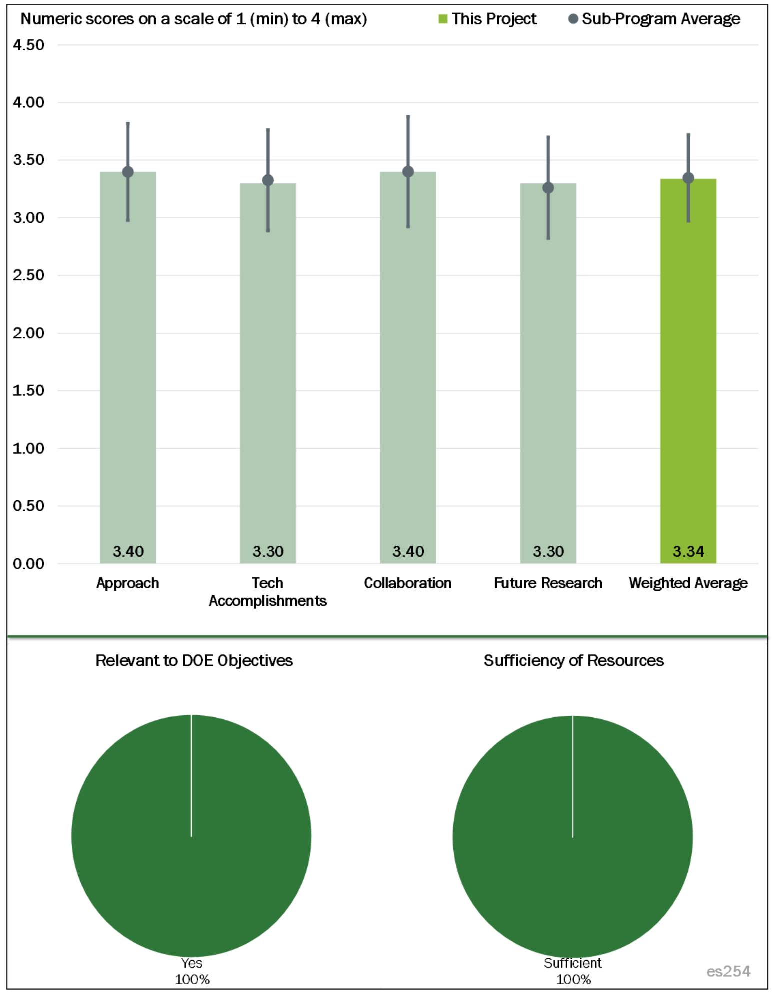

Figure 3-32 - Presentation Number: es254 Presentation Title: Enabling High-Energy/Voltage Lithium-Ion Cells: Materials Characterization Principal Investigator: Dennis Dees (Argonne National Laboratory)

Reviewer 1:
This reviewer commented that understanding and improving performance of cells at high potential is both extremely important and very challenging. The person further stated that this more fundamental approach is badly needed because Edisonian approaches have not and are not likely to work.

Reviewer 2:
The reviewer noted the approach states the intent and identifies three strategies that that will be employed. Two baseline high-energy/voltage cathode materials were considered for this evaluation.

Reviewer 3:
The reviewer said this work introduces magic angle spinning NMR as a tool to study Al coating and substitution which advances the understanding of Al role in the electrochemical performance of NMC and LCO electrodes.

Reviewer 4:
The reviewer mentioned that Ni-rich cathodes are very important for the development of advanced LIBs. The investigation and modification on these cathodes are urgently needed and timely. This person praised The PI for having made great progress on this project providing new insights and contributions to the field. The PI also developed surface sensitive characterization tools to probe and understand the interfacial compounds of Ni-rich materials. This reviewer noted that single crystal approach has been employed for a while from spinel to LMR and now Ni-rich. The only concern is how much knowledge gathered from single crystal can be used to address the challenges of the polycrystalline cathode materials. For this reviewer, the correlation is not quite clear.

Reviewer 5:
This reviewer noted that development of surface sensitive characterization tools, understanding the role of ceramic coatings, and studying single crystals are proposed in order to understand the interfacial reactions that lead to instability of Ni-rich electrodes.

Most of the ceramic coating studies were reported in 2016. The reviewer pointed out the outcome is not new and the approach of the project is similar to the ones previously reported in articles. For example, it has already been shown that thicker alumina coatings (more ALD cycles) result in poor performance. This person also stated wet methods to apply the coating have been previously reported, and warned there is not much uniqueness in the approach of the project.

Regarding the single crystal work, the reviewer commented that the particles are synthesized, but characterization of these particles seems to be very challenging.

Though the project has emphasis on the details of the mechanism of interfacial reactions, this person said the report lacks solid discussions on the possible mechanisms.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
This reviewer praised the excellent progress on understanding and tuning the properties of Ni-rich materials. The challenge was tackled from different aspects to obtain a whole map of accurate understanding. The person said the different coating effects of Al_2O_3 on NMC and LCO are discovered which is interesting and may be helpful for other materials modifications. Electrolyte decomposition has been studied and quantified which is critical to understand the interfaces. The reviewer pointed out the stoichiometry control of thin film NMC cathode by sputtering method may need to be addressed before any further modifications on as-prepared cathodes.

Reviewer 2:
The reviewer acknowledged this work made great progress on understanding effects of surface structure, Al coating and process history on the performance of electrode materials at high voltage.

Reviewer 3:
This person said the progress was mostly in the growth of the single crystal and for comparison to the model. The project results demonstrated an understanding of the parameters needed to effect crystal growth and then related the effect of crystal size, surface chemical composition and the particle surface facet.

Reviewer 4:
This reviewer commented it would be helpful to compare cycle life results of the materials synthesized in this program to commercially available materials. This person remarked more statistical rigor would also be useful.

Reviewer 5:
The reviewer noted the spectroscopy techniques used in surface studies are not necessarily novel, and it is not clear if any new feature in the existing techniques were developed with the exception that thin film samples providing more accurate and well-controlled data are used.

This person said the effect of ceramic coatings is already known, and the project should place more emphasize on understating the function of these coatings.

The reviewer commented that the single crystal work could provide valuable information, however, the feasibility of future experiments is not clear.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The person noted this project required excellent collaboration with the many teams involved in this project.

Reviewer 2:
This reviewer asserted the PI has collaborations with LBNL and NREL and that good team effort has been demonstrated.

Reviewer 3:
This reviewer said this work shows good collaboration and coordination with computational team and LBNL to understand facet effects on surface chemical composition and stability.

Reviewer 4:
The reviewer observed the project team is collaborating with different groups. More communication and exchange of results in regard to the ALD coating could be helpful.

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.

Reviewer 1:
The reviewer mentioned the proposed future work is well planned covering coating, cathodes, single crystal development and modeling as well as the electrolytes. It is suggested to integrate all the modifications on cathode materials into pouch cell design for further validation. This person pointed out the electrolyte work by another team needs to be accelerated to combine with coated Ni-rich cathode materials.

Reviewer 2:
This reviewer remarked that when studying the evolution of a coating (either Al- or T)-based), it would be great to determine the bulk solubility limit for Al or Ti substitution in NMC materials. This will help separate coating and doping effects when certain amount of Al or Ti is used to synthesize the targeted composition.

Reviewer 3:
This reviewer commented the future plans involve a lot of work with the other teams. The reviewer stated the statement was made by the PI that the target is titania-based coatings, but there was no clear explanation made on why the direction change. This person pondered whether the direction change meant that the Al coatings are being abandoned. That was not made clear to the reviewer.

Reviewer 4:
The reviewer observed that future plans are mainly focused on understanding the evolution of ceramic coatings, optimization of NMC thin films as a model system, and the completion of single crystal studies.

The use of titania-based coatings is suggested, but this should be given less priority compared to understanding the mechanism of alumina coating remarked this reviewer. It should also be noted that Ti unlike Al is a transition metal cation and might interfere with the performance of cell, and creates even more complications.

As mentioned by a reviewer, experimental methods necessary to study the single crystals should be planned according to the resolution needed to see the differences between different facets.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

This reviewer said this project is one of the key aspects of a larger project that will allow for improved battery performance.

Reviewer 1:
The reviewer mentioned that understanding electrolyte-surface interaction at high voltage is critical for battery materials development and help accelerate the EV adoption.

Reviewer 2:
This reviewer asserted that the project provides knowledge on the cathode surface reactions that lead to the degradation of LIBs, tries to find solutions to stabilize cathode surface/particles, and thus will accelerate the utilization of high-energy LIBs in automotive industry.

Reviewer 3:
This person commented 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 reviewer noted this project is part of a larger project and the funding is shared.

Reviewer 2:
The reviewer said the resources are sufficient for the project to achieve the stated milestones in a timely fashion.

Reviewer 3:
This person asserted the project team has access to sufficient resources and collaborations in order to perform the proposed tasks.

Reviewer 4:
The reviewer concluded that ANL and other collaborating laboratories have all the required equipment and facilities to perform the project.

Presentation Number: es261
Presentation Title: Next-Generation Anodes for Lithium-Ion Batteries: Overview
Principal Investigator: Dennis Dees (Argonne National Laboratory)

Presenter

Dennis Dees, Argonne National Laboratory

Reviewer Sample Size

A total of eight reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

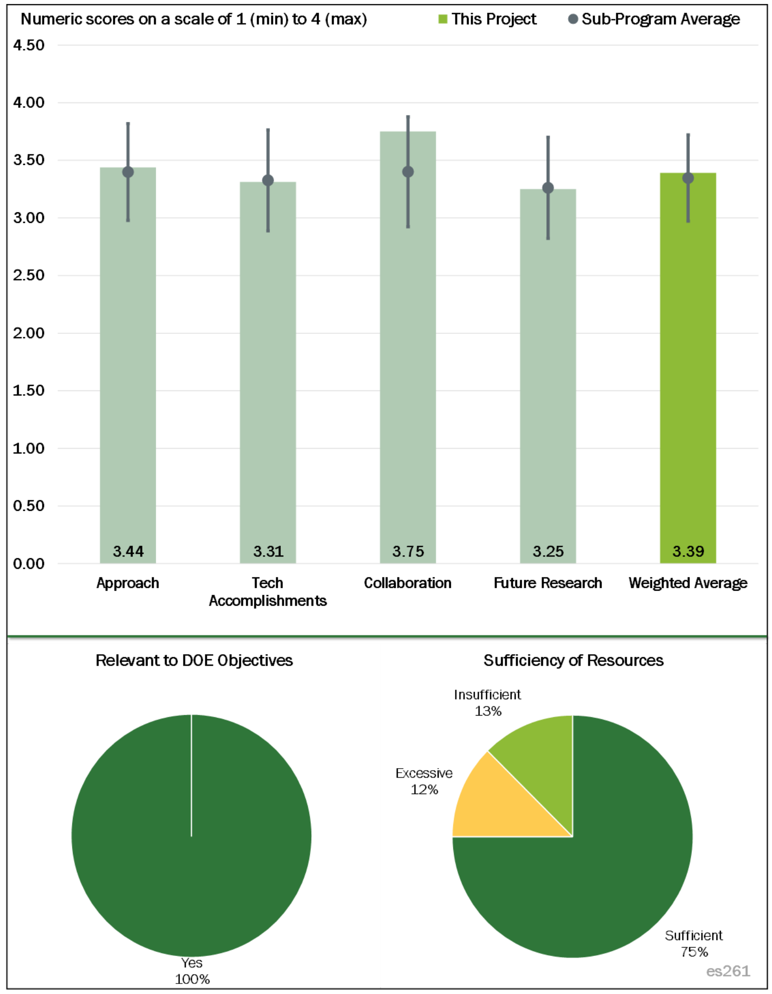

Figure 3-33 - Presentation Number: es261 Presentation Title: Next-Generation Anodes for Lithium-Ion Batteries: Overview Principal Investigator: Dennis Dees (Argonne National Laboratory)

Reviewer 1:

The reviewer remarked the project is an outstanding, comprehensive study on understanding Si in Li-ion systems.

Reviewer 2:

The reviewer expressed this is a very ambitious program to assess advantages, disadvantages and solutions for Si anode materials. It systematically investigates various aspects of materials, electrodes and use case scenarios.

Reviewer 3:

This reviewer observed the large multi-lab effort focused on overcoming cycling issues of high-capacity Si anodes, including silicon carbide (Si-C), particle size and Si SEI layer affects.

Reviewer 4:

This person praised the approach to performing the work as excellent. Detailed electrochemical and analytical diagnostic study plan are conducted. The anode advancements are verified based on full cell results which are rare in the community remarked this reviewer. The reviewer offered a few following suggestions. Firstly, because pack level benefits reach diminishing returns after 1,000 milli-Ampere hours (mAh)/cubic centimeter (cm^3) (Si with less than 75wt% graphite), the baseline may consider choosing Si (25%)/graphite (75%) in addition to 15% Si in the mixed anode. Secondly, the detachment of high Si content electrode from the substrate after cycling needs to be considered. Thirdly, because Si undergoes large volume change (i.e., increase of surface area after cycling), the impedance measured on the anode side always decreases, although SEI incured impedance increase accumulates with cycling. Therefore, this reviewer observed it is early to conclude that impedance rise on cycling is mainly at the positive electrode. More cross validation is needed to confirm this point. Fourthly, some of the team members used NMC while this poster uses NCM for Ni Mn Co. This has to be consistent within the team. Lastly, the reviewer questioned the ratio of electrode/electrolyte has been controlled when performing ARC testing and if that would be the possible reason for the large variation among different cells.

Reviewer 5:

The reviewer noted that this poster covers only a part of the work being done in the overall project on the development of Si materials for use in Li-ion cells. It is possible that concerns mentioned in this review are adequately addressed in other presentations which were not reviewed by this reviewer.

This reviewer commented that most aspects of the overall approach are very good. The scope of the project is wide ranging and comprehensive. This person noted the project attempts to address most major issues including particle size, choice of binder, methods of processing, nature of the SEI, important side reactions, etc.

The reviewer pointed out one weakness in the approach is that the commitment to doing publishable (i.e., public) work means that the project does not have full access to proprietary materials being developed by industry. It is possible that the first Si-containing materials to be incorporated into production cells will have been developed by industry and never evaluated in this "deep dive" effort. Given the tension between the goals of open publication and protection of proprietary information, this reviewer cannot suggest a solution to the problem, but the issue should be noted as a limitation on the scope of the work being done in this effort.

Reviewer 6:

This reviewer stated the multi-lab approach is quite comprehensive, addressing critical issues hindering the advancement of Si-C electrodes. One of the Remaining Challenges and Barriers" noted, "Particle cracking, particle isolation, and electrode delamination", would require additional effort to measure the mechanical properties of the Si-based electrodes and adhesion between Si particles and polymer binders. This person mentioned the project may benefit from collaborating with researchers in the mechanics of materials community.

Reviewer 7:

This reviewer expressed the approach lacks focus to some extent. The binder is varied, but the fundamental stability of the Si is suspect in all cases as witnessed by impedance, gassing, cycling, and thermal studies.

The reviewer concluded the project would benefit from a study of the patent literature which shows a number of methods of stabilizing the Si in the presence of graphite or carbons. Perhaps one of these methods would be a better starting point than simply ball milling the mixtures.

Reviewer 8:

Although the study of Si-based materials is intrinsically of interest, this person commented the materials studied are not competitive with the most advanced Si anodes, such as those being produced by Amprius and Sila Nano. These companies are now producing at significant volumes and will be commercialized shortly. Instead, this person observed the sort of materials being studied seem unlikely to be commercialized.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This reviewer acknowledged the excellent progress on this challenging topic. The team evaluated different commercial sources of Si as well as their lab made Si model system to understand the fundamental mechanisms underneath. This person remarked there was a clear path to compare the results using standard protocols and the key issues that the team should focus on, while different tasks are assigned. There were many publications and presentations last year to disseminate the knowledge gathered. The reviewer observed more solutions need to be proposed in addition to the diagnosis approaches considering the large amount of published knowledge.

Reviewer 2:
The reviewer noted that this poster covers only a part of the work being done in the overall project on the development of Si materials for use in Li-ion cells. It is possible that concerns mentioned in this review are adequately addressed in other presentations which were not reviewed by this reviewer.

Based on the information in this poster, the reviewer concluded good progress is being made; and all critical milestones are being met. It is very clear that the benefits of Si-containing materials are balanced by the challenges of getting these materials to function in cells that meet the DOE's goals for cycle and calendar life.

This reviewer further commented that the large amount of work being done on many aspects of the materials by multiple labs, makes it challenging to absorb a full understanding of all of the results that are being obtained. Multiple, focused papers in the open literature serve to document specific areas of the total project. This reviewer hopes that an overall, coherent, review of all of the work and results will be prepared before the project ends.

Reviewer 3:
This reviewer asserted the project was on path to address its milestones/goals in a number of areas, showing good progress on understanding Si on graphite (Gr), SEI layer and particle size impacts, but noted it appears ORNL milestones have been delayed. The reviewer noted there were interesting results on Si-Gr cycling and Raman mapping of inactive Si.

Reviewer 4:
This reviewer acknowledged a great deal of very high-quality work has been done. Binder development is very important. This person was not sure how much the surface coating program is adding to the very large literature.

Reviewer 5:
This person observed this is an extremely large project. Certain areas are advancing more quickly than others. The presentation materials do not provide sufficient details on the “twenty-five milestones” for this reviewer to have a more complete understanding of the accomplishments and progress.

Reviewer 6:
The reviewer noted many interesting results were presented. However, the results seem to be mostly an initial evaluation and do not show progress along the multiple directions of investigation. This reviewer stated the work should be more iterative.

Reviewer 7:
This reviewer remarked that while there are some good results, they are overshadowed by the lack of stability of the Si in the experiments.

Reviewer 8:
The reviewer pointed out many, many issues both known previously and discovered have been presented. This person questioned whether there are actually solutions to these problems. Some perspective from the authors would be useful. The reviewer pondered how much more effort is needed to make high Si content electrodes feasible, whether it is worth the effort or if there are other (solid state with li-metal) more viable approaches.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer praised the terrific set of collaborators.

Reviewer 2:
This person remarked the whole team is collaborating very well with each other. Frequent communications and focused effort on the key challenges are demonstrated.

Reviewer 3:
This reviewer observed this was a multi-lab effort with numerous collaborative interactions.

Reviewer 4:
This reviewer noted that there are many collaborations that are excellent and pondered whether there are meetings of all of these collaborators to try to set directions of the program.

Reviewer 5:
The reviewer noted that this poster covers only a part of the work being done in the overall project on the development of Si materials for use in Li-ion cells. It is possible that concerns mentioned in this review are adequately addressed in other presentations which were not reviewed by this reviewer.

The person stated this poster and supporting information clearly shows the roles of the several national laboratories working on this effort. This poster also references other posters that are reporting aspects of the overall project.

The reviewer observed that while the poster does not document exactly how coordination is being done (such as meetings, teleconferences, or cross-lab staff), the implication is that the process is going smoothly.

Reviewer 6:
The reviewer said this program is a great example synergistic collaboration of national laboratories, and good use of their resources. However, it would be wise to include a commercial battery manufacturer, even if only for the feedback related to the practical use of Si materials. This person pointed out that effects such as gas generation during slurry mixing, cell swelling between charged/discharged states, calendar life etc. are very relevant in manufacturing and use of cells, but may be overlooked in early material development.

Reviewer 7:
The reviewer stated the project can be further enhanced by collaborating with experts outside the national laboratories, especially in the area of mechanical measurements, including coupled electrochemical-mechanical properties and interface adhesion.

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.

Reviewer 1:
The reviewer noted that this poster covers only a part of the work being done in the overall project on the development of Si materials for use in Li-ion cells. It is possible that concerns mentioned in this review are adequately addressed in other presentations which were not reviewed by this reviewer.

The reviewer noted this is a large, complex effort; but the proposed future work is reasonable to address the challenges of the material.

Reviewer 2:
This reviewer stated there was an appropriate continuation of effort, albeit with limited description.

Reviewer 3:
This reviewer praised the outstanding suite of diagnostics, but noted concern that state-of-the-art Si compounds are not on the horizon.

Reviewer 4:
The reviewer expressed that the future work is planned in detail with many milestones in each institution. While the direction is correct, this reviewer had a few comments on the proposed research. The reviewer suggested that whether or not polypyrrole (PPy) can be used for Si/graphite with significant improvement needs to be determined. Otherwise, PPA or LiPPA will be worth more effort. ALD or MLD coating has been explored for many years. Considering the cost and the effects of coating, will this technique be eventually adaptable by industry needs to be answered. The reviewer stated that probably a few communications with industry can help determine the go/no-go on this coating approach, or whether alternative coating methods should be planned. The reviewer also recommends 25% Si be included in the map because 15% Si still cannot meet the goal according to the PI's simulation results.

Reviewer 5:
The reviewer observed that one of the Remaining Challenges and Barriers namely “Particle cracking, particle isolation, and electrode delamination” is not addressed under “Future Work.”

Reviewer 6:
This reviewer recommended more iterative than exploratory research.

Reviewer 7:
The reviewer would like to see a real effort to review the literature (including patent literature) to find a better starting point for the project, particularly with respect to protecting and stabilizing the Si surface from the processing steps.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
This reviewer noted improved battery performance will advance vehicle electrification and thus displace petroleum consumption.

Reviewer 2:
This person stated this project supports the overall DOE objectives.

Reviewer 3:
The reviewer expressed that a high-energy anode is very much in support of DOE objectives.

Reviewer 4:
The reviewer noted that this poster covers only a part of the work being done in the overall project on the development of Si materials for use in Li-ion cells. It is possible that concerns mentioned in this review are adequately addressed in other presentations which were not reviewed by this reviewer.

This reviewer noted it is generally agreed that to meet the DOE's goals of reduced cost and improved energy density and specific energy, cells incorporating new materials and fabricated using new manufacturing techniques will be required. Current Li-ion technology has maximized the performance of “standard” graphite electrodes. Further improvement in the negative electrode's performance will require new materials such as Si or Li metal remarked the reviewer. This project addresses this need for new materials.

Reviewer 5:
This reviewer stated the project was 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 said the national laboratories have more than sufficient resources to conduce the project.

Reviewer 2:

This reviewer noted the large lab effort results in large overall budget, albeit split among the labs.

Reviewer 3:

The reviewer noted that this poster covers only a part of the work being done in the overall project on the development of Si materials for use in Li-ion cells. It is possible that concerns mentioned in this review are adequately addressed in other presentations which were not reviewed by this reviewer.

This reviewer said the large number of cooperating laboratories means that this project has access to an extensive set of facilities and a large group of knowledgeable scientists and engineers. The budget, of $3.6 million for FY 2017 reflects the large scope of the project.

This reviewer stated there is no question that facilities and staff should be adequate. No financial details are provided, but the reviewer inferred that the funding is adequate to support the facilities and staff.

Reviewer 4:

The reviewer observed the team has accomplished a very large amount.

Reviewer 5:

This person said the resources were okay.

Reviewer 6:

This reviewer mentioned mechanical property measurements may be added.

Presentation Number: es262
Presentation Title: Next-Generation Anodes for Lithium-Ion Batteries: Fundamental Studies of Si-C Model Systems
Principal Investigator: Robert Kostecki (Lawrence Berkeley National Laboratory)

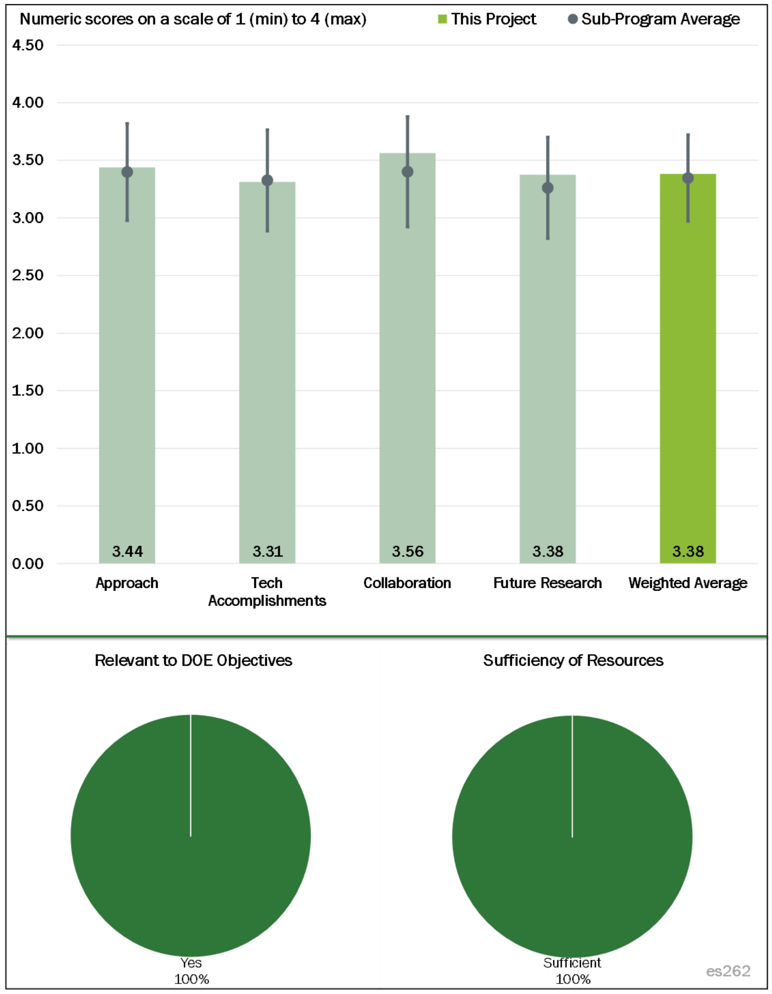

Figure 3-34 - Presentation Number: es262 Presentation Title: Next-Generation Anodes for Lithium-Ion Batteries: Fundamental Studies of Si-C Model Systems Principal Investigator: Robert Kostecki (Lawrence Berkeley National Laboratory)

Presenter

Robert Kostecki, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of eight reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

This reviewer stated the mechanical properties of the binders in electrochemical environment are known to be important and should be measured.

Reviewer 2:

The reviewer noted this project as an interesting fundamental approach to the real, practical issue of binder selection for Si based systems.

Reviewer 3:

This person concluded the project was a very thorough effort to understand and mitigate the problems of Si-C anodes. It is very well-integrated with other advanced anode projects.

Reviewer 4:

The reviewer said Si anodes are a critical enabler to achieve DOE goals for energy storage. The approach, systematic and in collaboration with other national laboratories, seeks to address many of the technical barriers that Si anodes still have to pass to become a practical anode material.

Reviewer 5:

This person observed the project team was working on addressing issues of high-capacity Si anodes while focused on model Si electrodes and the effect of binders, including *in situ* and *ex situ* characterization.

Reviewer 6:

The reviewer noted that this poster covers only a part of the work being done in the overall project on the development of Si materials for use in Li-ion cells. It is possible that concerns mentioned in this review are adequately addressed in other presentations which were not reviewed by this reviewer.

The reviewer affirmed the overall approach is systematic and reasonable. Results provide a basic understanding of issues associated with Si electrodes and binders. This person pointed out that because most of the reported research was done on model systems, the results may not always reflect what happens in production cells. This fact should be recognized, but it does not invalidate the work reported. The reviewer further acknowledged it might be or would be difficult to impossible to make the basic measurements reported in this poster on production cells.

Reviewer 7:

This reviewer asserted the PI is using a model of the Si/PPy electrode to understand the binder effects for a Si anode. Binder is known to be very critical for Si anode. The person commented the project provides very good understanding on the interactions among Si, binder and electrolyte. The adhesion ability of polyacrylic acid (PAA), PPy and as polyvinylidene fluoride (PVDF) binders to Si wafer are compared systematically. The reviewer observed processing conditions are revealed to largely affect the binder adhesion. This person suggests the project team investigate the binder adhesion to Si after cycling. The reviewer pondered whether PPy will still provide good adhesion of Si and Cu after repeated cycling. For the purpose of evaluation of PPy stability under electrochemical reactions, this person suggests the project team to use PPy mixed with carbon.

Reviewer 8:

The reviewer remarked the approach using a Si wafer is a good one to obtain fundamental information regarding the Si/binder interface because a number of experimental methods are now possible that would not be useful for particulate Si such as attenuated total reflectance geometry Fourier transform infrared (ATR-FTIR) spectroscopy and atomic force microscopy (AFM). This person would have been happier to see a conventional binder such PVDF used rather than the PPy, which has not been characterized for such properties as molecular weight, degree of polymerization (such as is this a copolymer with PAA), etc. This reviewer also noted it is important to establish the absorption of electrolyte into the polymer.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This person said the project team prepared model Si electrodes and evaluated interfacial phenomena with binders, from *in situ* spectroscopic and electrochemical analysis to mechanical properties. The reviewer concluded the results were on track with regard to milestones.

Reviewer 2:

The reviewer said the data presented in the report are clearly presented and analyzed, including results that may not be considered positive toward a practical solution. However, they are relevant to understanding the mechanisms and interactions between Si materials, binders and electrolyte. This person pointed out this study not only determines the mechanism of PPy interactions in composite Si electrodes but also offers insights into rational design principles of advanced multifunctional binders for intermetallic Li-ion anodes.

Reviewer 3:

This reviewer asserted that all deadlines seem to have been met in a timely fashion. Progress is appropriate.

This person remarked that this part of the larger project is clearly designed to focus on “Fundamental Studies.” These studies will produce data that will improve the understanding of Si-C systems. Because the studies are “fundamental” in their scope and design, the reviewer pointed out additional work will be required to transition these results from “model systems” to production cells. To the extent that DOE goals are focused on production cells, this project is one (or more) step(s) removed from having direct applicability to meeting these goals.

However, the reviewer stated it is reasonable to assume that other efforts within the larger project will help with this transition.

Reviewer 4:
This reviewer concluded the results themselves are really excellent for this project. This person was especially impressed with the studies on conducting binders.

However, the Si anodes closest to commercialization (and they are very close) are not mentioned. These are the anodes produced by Sila Nano and by Amprius, both of which should be available in electronic devices within about a year. The reviewer concluded ignoring these products is an important shortcoming of this project.

Reviewer 5:
The reviewer observed results were presented at many conferences, though there were few peer-reviewed publications. The PI should publish the results in peer-reviewed journals to disseminate the results the reviewer commented.

Reviewer 6:
This reviewer noted that some new findings on the binders are uncovered, providing new insights on the effects of binders on Si anode performances. This project concluded that the intake of diethyl carbonate (DEC) solvent by PPy causes the formation of instable SEI on Si. Because the amount of PPy to be used in practical electrode will be much less than in the model electrode, this person pondered whether the DEC intake effects will still be a big concern. The AFM imaging may help extract the thickness information of SEI layers at different potentials. For this reviewer, it was hard to tell the difference in Si/PPy electrode below 2.25V simply from a morphology point of view.

Reviewer 7:
As in the approach, this person was concerned about the use of PPy as the test material rather than a more well studied binder such as PVDF. The reviewer agreed that an aqueous based binder can give problems of oxidation of the Si surface, particularly for nanoparticle Si, which will lead to a very high level of irreversible capacity.

Reviewer 8:
The model system (Si wafer) is interesting but this person wondered whether it is a practical representation for actual electrodes. The reviewer pondered if the binder coating on Si-particles is conformal and questioned if the results would be substantially different if the coating was patchy.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer observed this program is interfaced with a number of other efforts to make Si work to give something like 1,000 Ah/kg activity in a carbon Si electrode, so the project features excellent collaboration with other institutions.

Reviewer 2:
This person noted that this project involves multiple laboratories and many scientists and engineers and this poster indicates how this particular project fits into the collaborative effort.

Reviewer 3:
The reviewer said there was good collaboration with other team members. The binder was supplied by Gao Liu at LBNL.

Reviewer 4:
This reviewer acknowledged the project was collaborating with a number of national laboratory groups/PIs.

Reviewer 5:
This reviewer commented there is a huge list of contributors, but there is no indication of the extent of their involvement in the project. Extensive interactions with other national laboratories were noted by this person.

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.

Reviewer 1:
The reviewer praised the excellent well described future research in three thrusts.

Reviewer 2:
This person stated the three areas of research planned address well the directions of work toward project goals.

Reviewer 3:
The reviewer stated this is an ambitious, but worthwhile proposal for future work.

Reviewer 4:
This person observed the proposed future research is described well in multiple slides.

Discussion of future work does not provide details on how these fundamental studies will be used to help guide the development of production-type cells.

Reviewer 5:
This reviewer concluded these were well thought-out plans, but there is no mention of the most likely winners in the race to produce commercial Si anodes.

Reviewer 6:
This person remarked the PI provides very detailed future work plan which is also well integrated within the whole focus team. The binder effects in the X-Y directions of the electrode (currently it is focusing on Z-plane i.e., perpendicular to the Cu substrate) also needs to be considered, which is very critical for thick Si-C electrodes. The reviewer said the project team needs to determine if PPy will be eventually employed in the final deliverables or if PPA will be adopted. Alternatively, electrolyte recipes may need to be altered to best match PPy binder.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
This person pointed out improved battery performance will advance vehicle electrification and thus displace petroleum consumption.

Reviewer 2:
The reviewer noted this project systematically investigates the binder effects for Si anodes. Model systems help much towards the accurate understanding of the system. This person concluded the project supports the overall DOE objectives.

Reviewer 3:
This reviewer commented it is generally agreed that to meet the DOE's goals of reduced cost and improved energy density and specific energy, cells incorporating new materials and fabricated using new manufacturing

techniques will be required. Current Li-ion technology has maximized the performance of "standard" graphite electrodes. The reviewer said further improvement in the negative electrode's performance will require new materials such as Si or Li-metal. This project addresses this need for new materials by investigating fundamental processes in Si-C model systems.

Reviewer 4:
This person asserted the project was clearly relevant.

Reviewer 5:
This reviewer said yes, Si anodes can enable high energy density and specific energy batteries that will increase the adoption of electric vehicles.

Reviewer 6:
This reviewer expressed the project was okay to the extent that these sorts of electrode materials are not made irrelevant.

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

Reviewer 1:
The reviewer concluded the staff and facilities at LBNL in collaboration with the other laboratories and scientists working on this project are clearly adequate to do the proposed work.

Although detailed financial data are not included in the poster, this reviewer assumed from the progress that is being made that the funding is adequate.

Reviewer 2:
This person mentioned that LBNL has sufficient facilities to carry out the proposed work including synthesis and characterizations. In addition, the PI has collaborations with other institutions and thus access to the equipment that may not be immediately available at LBNL.

Reviewer 3:
The reviewer stated the resources were appropriate given budget limitations.

Reviewer 4:
This person said the resources were okay.

Presentation Number: es263
Presentation Title: Electrodeposition for Low-Cost, Water-Based Electrode Manufacturing
Principal Investigator: Stuart Hellring (PPG)

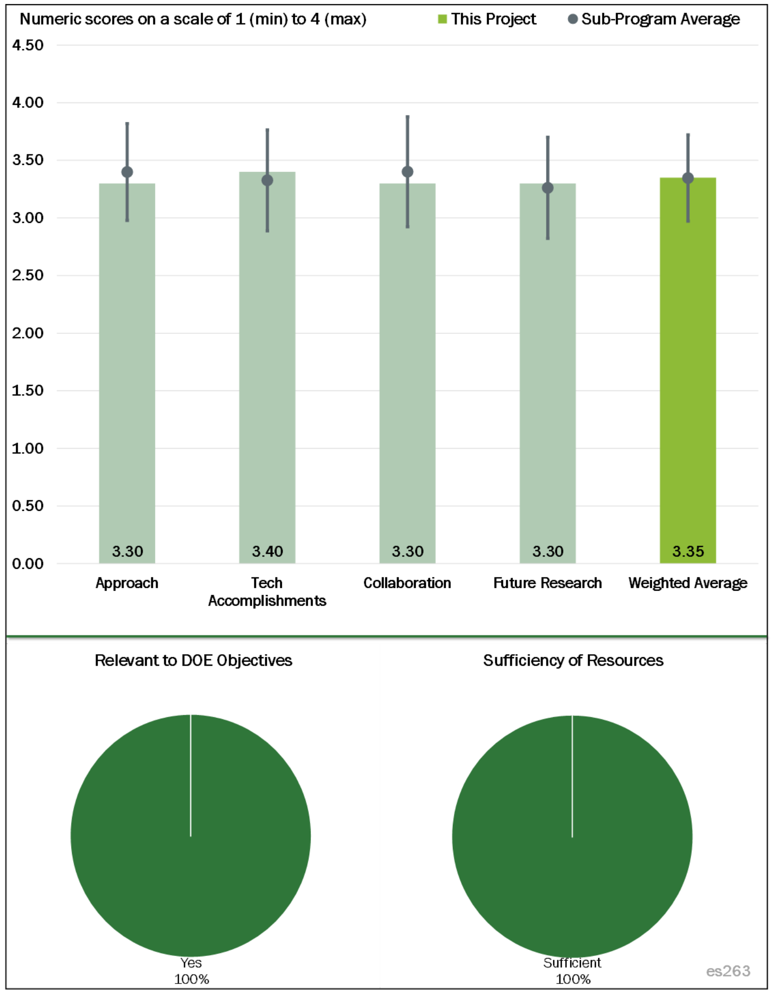

Figure 3-35 - Presentation Number: es263 Presentation Title: Electrodeposition for Low-Cost, Water-Based Electrode Manufacturing Principal Investigator: Stuart Hellring (PPG)

Presenter

Stuart Hellring, PPG

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said the approach for deposition of Li-ion electrodes from water is very unique. Many of the previously recognized barriers and problems can be effectively overcome with the proposed steps.

Reviewer 2:

This reviewer stated that the project "Gant-Chart" included in 2016 poster slide-deck and reference in 2017 editions reveals a well-considered program, with logical time-lines assigned for each established milestone event/task. Initial experimental work demonstrates the adequacy of this planning process, although this person remarked it would be useful to include task assignments for all participants in this effort.

Reviewer 3:

The reviewer asserted the water based electrodeposition is very attractive approach. It would help if practical challenges (which are significant) to achieving this are better outlined.

Reviewer 4:

The reviewer observed that battery performance is limited to only 50 cycles. Even at C/3 rates this would only be a 10-day test. This person would like to see more electrochemical testing. The reviewer does not think 50 cycles are far enough to determine there is no loss in cyclability long term (especially for automotive long term). This reviewer said the project seemed to demonstrate a good approach to improving coating performance, but having only one material show good discharge capacity after 1-15 cycles even though materials should be similar from different vendors is not encouraging. It was difficult for this reviewer to determine if the project team understands the underlying mechanism for the one good result. The project talked about additional active material coatings to avoid Li leaching, but this person's preference is for the manufacturing process to adjust to suit the material that performs well electrochemically, rather than have a material that needs to be modified (and possibly affect electrochemical performance) in order to be processed. It is still unclear if production rate even with double sided coating will be fast enough to overcome the slow nature of the electrocoat process. This reviewer understands that it is "tunable" but there has to be an upper bound for coating speed, and this person cannot judge if that is acceptably fast or not.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer remarked that the work is progressing in reasonable agreement with the initial work schedule. Besides selection of a material set, the process has demonstrated feasibility of the electrodeposition process in coating battery substrate materials. This reviewer noted that many process hurdles and challenges remain to be addressed (e.g., coating homogeneity, dual-side coating, etc.) and significant challenges are expected as the process is scaled to a "larger size-scale".

Reviewer 2:
The reviewer would appreciate more focus on demonstrating good cycling and rate capability for extended time. While the reviewer understands that this is still part of the work plan so may be a non-issue, this person stated it would be nice to know if it's an issue as soon as possible.

Reviewer 3:
This reviewer considered if there is a way to more fundamentally understand the differences observed between different NMC supplies.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer asserted that the project team reports considerable interaction between PIs at ORNL, ANL and private industry (PPG and Navitas) as well with SMEs from other sectors.

Reviewer 2:
This person noted that collaboration exists and is described in the poster, but, if possible, the developer and supplier of active material should be more deeply involved in the solving of some questions, such as why only one active material from the variety of similar types can be used effectively.

Reviewer 3:
This person mentioned that collaboration with battery makers may strengthen this project.

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

Reviewer 1:
The reviewer noted the original schedule contains relevant metrics for years 2 and 3. However, review of FY 2016 presentation poster "slide-deck" does not indicate any edit to original milestone events. Instead, the reviewer commented this document, which is a "living" document, should be routinely updated to address envisioned new knowledge, as the project progresses. Presentation of "future" effort is presented, but it seems overly broad and high level. The reviewer said additional details would have been very useful.

Reviewer 2:

The reviewer recognized this question should have been asked during the review, but now wonder if PPG is doing any work towards electrocoating anodes as well. If there is a truly compelling reason to replace the traditional coating equipment with electrocoat maybe there is a future application for this technology, but if the end goal is to only replace cathode coating the traditional coating equipment would still be required for anode, then the full (proposed) cost and factory floor space savings would not be realized, needing two coating systems in one factory. If anode electrocoating is planned, this person pondered whether this would be easier than cathode considering no Li leaching, or whether there is a reason a materials anode electrocoat process would not work. (The reviewer apologized for not thinking of this during the discussion).

Reviewer 3:

The steps are correct but this reviewer was concerned that without more and deeper understanding of the fundamentals (difference in performance between commercial materials, effect of residual moisture, uniformity of deposited layers, etc.) scale-up will be difficult.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

This reviewer remarked that assuming cost projections are accurate, any cost reductions will help. This project seems like it has a long way to go in development compared to the highly optimized methods currently used for coating at speed. Also, the reviewer pointed out a need to understand the failure mechanisms the project team is seeing, because if it only works with a small number of active materials the investment will not be appealing compared to a more flexible process.

Reviewer 2:

The reviewer stated that the introduction of LIBs within the transportation sector will result light-weighting of designed vehicles which serves to conserve energy, whether it be petroleum or other based energy source. However, this project is one which is focused on energy storage, regardless of generating source. Further, the reviewer noted this project is more focused on enabling a more cost-competitive process route which can be used to manufacture batteries. Thus, this person concluded this project is more focused on process cost than petroleum displacement.

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

Reviewer 1:

This person concluded the project seems fully supported.

Reviewer 2:

The reviewer said the project team represents a collaborative effort between national laboratory and private industry. As such, researchers have access to a wide variety of tools and resources to support conduct of this effort.

Presentation Number: es264
Presentation Title: Li-Ion Battery Anodes from Electrospun Nanoparticle/Conducting Polymer Nanofibers
Principal Investigator: Peter Pintauro (Vanderbilt University)

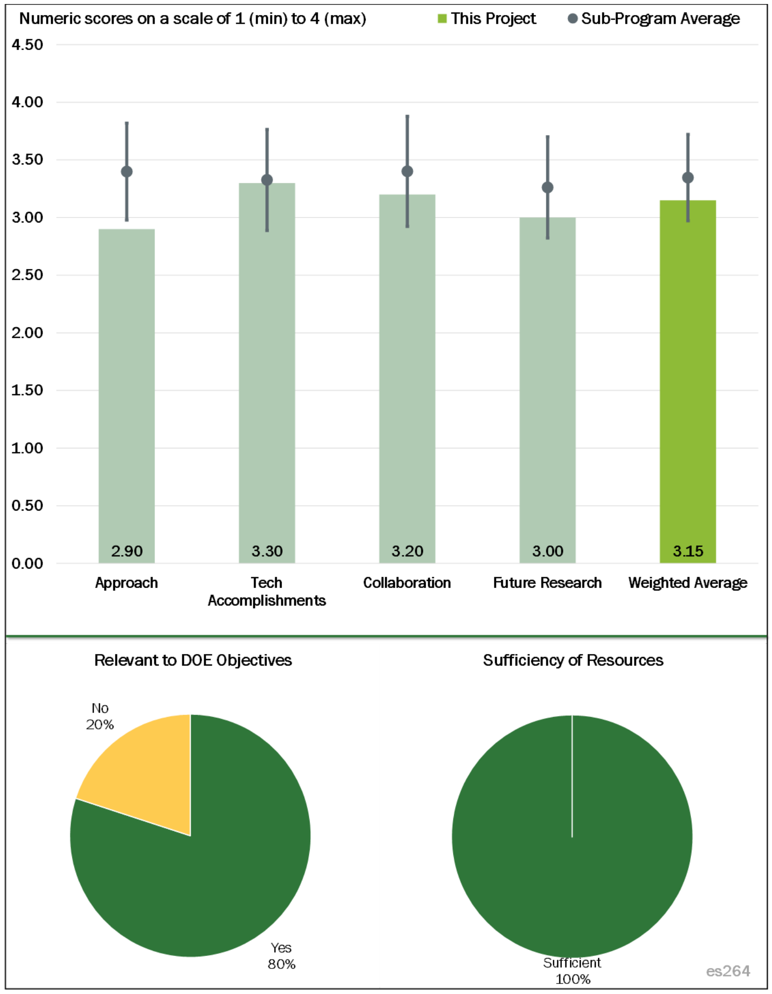

Figure 3-36 - Presentation Number: es264 Presentation Title: Li-Ion Battery Anodes from Electrospun Nanoparticle/Conducting Polymer Nanofibers Principal Investigator: Peter Pintauro (Vanderbilt University)

Presenter

Peter Pintauro, Vanderbilt University

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

This reviewer commented collaborative laboratory and private industry team is addressing well defined issues germane to battery technology. Among the issues are performance impact due to binder system, density, thickness, Si content, conductivity etc. The reviewer affirmed the project has been designed to address all in logical fashion, gaining valuable knowledge with each milestone event.

Reviewer 2:

This reviewer asserted that it seemed like a highly promising approach. The reviewer inquired about the long-term cycling result (e.g., 1,000 cycles) and the degradation mechanisms.

Reviewer 3:

The reviewer mentioned the project currently has achieved 750 mAh/cm^3 volumetric capacity with a final target of 800 mAh/cc for the anode only. This person would not expect full cell volumetric energy density to meet goals. For example, USABC goals for anode active materials is 1,800 mAh/cm^3. While it may be acceptable on a gravimetric basis, many automotive engineers would argue that having enough space for the battery is more difficult than enough volume. This reviewer said there are ways to make a more traditional Si anode more porous than is currently designed that could use the same equipment and processes that are already place, but are not pursued by cell manufactures because the resulting impact on energy density is untenable. This seems to be a further extension of that potential design, but to an extreme and using new equipment. The reviewer observed that current densities for most tests is also very low, and this person has questions about manufacturing this at a scale that would support vehicle production volumes at a reasonable price. There is very high content of inactive materials (conductive additive, binder).

Reviewer 4:

This reviewer pointed out the main failure mechanism of Si based electrode is the intrinsic mechanical fracture from Si. Nanofiber mats will not provide an effective mechanical protection, or otherwise, the team did not state clearly how the nanofiber mats can improve the cycle stability.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This person said solving issues with Si anode would greatly enhance commercial viability of electric vehicles.

Reviewer 2:

The reviewer commented that the project team has made significant discovery regarding most all variables laid out in the project planning stage. Relationships have been established between density, capacity, anode/cathode mat type (slurry versus fiber), etc. This person acknowledged that significant information has been gained regarding alternative polymer systems being used and process approaches to yield a range of fiber physical characteristics. It does seem that electro-spinning to create fine-dense fiber mats offers a unique approach to fabricate functional anode/cathode systems for an LIB. The reviewer would suggest that in addition to work current within the project that scale-up approaches, such as roll to roll be considered. Overall, the project team is meeting milestone events, on-schedule and finding positive results which justifies the effort done and envisioned for this project.

Reviewer 3:

This reviewer mentioned the program seems to meet goals laid out at beginning of project, but this person is not sure those goals are good enough to meet ultimate DOE goals.

Reviewer 4:

This reviewer warned that the testing results did not show the cycle efficiency, which could be most important in order to see the improvement.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

This reviewer noted the project team reports considerable interaction between PIs at Vanderbilt University, ORNL, LBNL and private industry i.e. e-Spin Technologies, Inc., as well with SMEs from other sectors.

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.

Reviewer 1:

The reviewer remarked that the project team describes a sound set of endeavors to investigate over the next time-period. Each will add to the knowledge base for this technology application, which will prove very positive. However, this person stated a review of all work to-date should be conducted and then compared to work accomplished by other researchers. It seems that the wealth of knowledge resulting from this effort will allow for establishment of new priorities and paths to follow. The reviewer asserted that this revised roadmap should then be integrated into the work plan, accordingly.

Reviewer 2:

This reviewer stated volumetric energy density should be considered, or the porosity of the nanofiber mats should be controlled in order to meet DOE's required volumetric energy density.

Reviewer 3:
This reviewer observed that it seems difficult to build actual cells with any power capability, no current collector. Highly porous nature of electrode means more intimate contact with electrolyte. This person mentioned that SEI growth is already a big problem for Si anodes, and it would seem a great deal of effort will need to be focused on forming a highly stable SEI layer or electrolyte-Si compatible pair that will not lead to high impedance growth and loss of capacity. Even if there is room for Si to grow, the reviewer pointed out the SEI will still crack and be in very intimate contact with electrolyte for further degradation. Longer cycling tests needed to demonstrate automotive capability.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer asserted that the introduction of LIBs within the transportation sector will result light weighting of designed vehicles which serves to conserve energy, whether it be petroleum or other based energy source. However, this project is one which is focused on energy storage, regardless of generating source.

Reviewer 2:
This reviewer said improvement in anode remains one of the key challenges for widespread adoption of battery powered vehicles.

Reviewer 3:
This reviewer pointed out the cost advantage is not demonstrated, energy density advantage negated on a volumetric basis. The use of Si does not guarantee a high-energy density electrode if the design is highly porous and has high percentages of inactive components.

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

Reviewer 1:
The reviewer expressed that the collaborative laboratory team has access to a wide variety of tools and resources to support conduct of this effort.

Presentation Number: es265
Presentation Title: UV Curable Binder Technology to Reduce Manufacturing Cost and Improve Performance of Lithium-Ion Battery Electrodes
Principal Investigator: John Arnold (Miltec UV International)

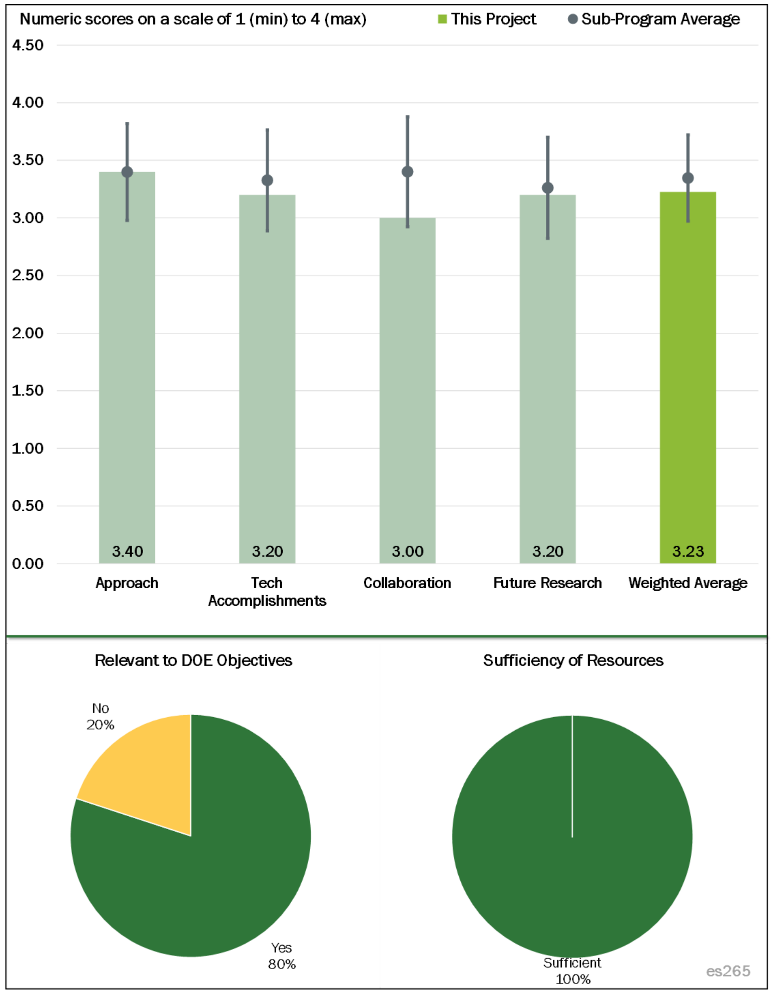

Figure 3-37 - Presentation Number: es265 Presentation Title: UV Curable Binder Technology to Reduce Manufacturing Cost and Improve Performance of Lithium-Ion Battery Electrodes Principal Investigator: John Arnold (Miltec UV International)

Presenter

John Arnold, Miltec UV International

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer loved the approach of using printing technology and ultraviolet (UV) curing to decrease cost of manufacturing and possibly increase performance of electrodes. The use of multiple layers to enable thicker electrodes is good, and has a secondary benefit of allowing for the possibility of gradient-type electrodes in which the formulation of different layers is changed.

Reviewer 2:

This reviewer praised the interesting work to reduce the cost of battery.

Reviewer 3:

This reviewer expressed that UV curing is attractive approach if it can be made practical.

Reviewer 4:

The reviewer asserted that UV curable binder technology could be significant advantage over conventional drying process in size and cost of capital equipment as long as there is minimal additional cost of precursors. Approach is to demonstrate efficacy of this.

Reviewer 5:

This reviewer commented that the initial project design incorporated a path to investigate potential means to discover polymer system which would outperform current generation materials at a lower overall manufacturing cost. As such, schema was developed to investigate alternative UV cure materials at same and lessor polymer content using processes which could offer greater throughput capacity at lessor cost. This person said the basic project outline was well-considered, providing a path to investigate representative state-of-the-art UV polymer system in such manner as to enable valid comparison to current state-of-the-art processing. Work plan was established so as to limit degree of equipment modification needed to perform experiment work, allowing experimental effort to be performed using existing facility and equipment. The reviewer concluded that work plan and milestones were established which were reasonable and per DOE Office of Energy Efficiency and Renewable Energy (EERE) APM, go/no-go events were established.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
This reviewer observed that this work determined that UV polymer systems can be used to substitute for existing materials, whether processed using a single side or dual side coating approach, when applied at 1 micron (μ) thicknesses. Although discussion regarding extent of polymerization, variation of coating thickness and compositional homogeneity, deposition process rate, etc. is presented, this reviewer commented that only very limited detail is presented. Details presented do not show any distinct advantage to using the process approach under investigation, other than a brief discussion regarding "cost". However, the reviewer noted that not presented is comparable cost involved to enable dual-side traditional polymer coating system or the capital expenditure cost for UV cure processing systems. Thus, this reviewer concluded although the project appears on-track in accomplishing established milestones, there is no go/no-go event requiring a decision whether or not to continue this endeavor, based on a Technology-Economic Analysis (TEA) of the proposed process approach.

Reviewer 2:
This reviewer pointed out that initial results indicate this approach is comparable or possibly better than conventional, however, additional data are necessary (two points to make a line e.g., Slide 11 is not sufficient).

Reviewer 3:
This reviewer has a concern about the need to calender these electrodes so highly in order to get adequate electronic contact. The project team might consider some kind of carbon-rich coating of the current collector. Another concern the reviewer brought forth is that testing of the films produced so far seems sparse (repeated testing would allow error bars on the data so there is indication that results are not just for the single "best case"). This person would like to see the project team get samples in the hands of other researchers so the products of the manufacturing process can be more rigorously tested and publicized at conferences.

Reviewer 4:
This reviewer concluded there was good technical accomplishment for NMC cathode with UV binder, stable capacity with cycle.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated the project team reports considerable interaction between PIs at ANL, ORNL and private industry i.e. Miltec UV International, as well with SMEs from other sectors.

Reviewer 2:
The reviewer said it looks like good collaboration with ANL and ORNL to validate results.

Reviewer 3:
This person noted it appears to be two individuals at national laboratories who tested films. There should be more testing done.

Reviewer 4:
This person concluded additional collaboration with battery makers would strengthen this project.

Reviewer 5:
This reviewer said the project needs more 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.

Reviewer 1:
The reviewer affirmed the project team presents some very "high-level" next steps and challenges which to investigate during the next funding period. Greater detail needs be provided to allow for better understanding of how and the rationale behind the proposed effort. The reviewer commented this should be provided to assure reviewers that work is being performed for a justifiable reason.

Reviewer 2:
This reviewer said the future work is appropriate, especially the need to demonstrate with thicker coatings, but this person would like to see more validation of results as well efficacy with different electrode materials.

Reviewer 3:
This reviewer liked the idea of using letterpress as well as slot die technologies, as well as attempts to decrease additive load. Plans to do long-term cycling are essential remarked the reviewer.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
This reviewer asserted that improved batteries will advance vehicle electrification and thus help displace petroleum.

Reviewer 2:
This person confirmed reducing battery manufacturing cost would significantly benefit adoption of battery powered vehicles.

Reviewer 3:
This reviewer concluded the project is relevant because batteries are used for EVs and PHEVs.

Reviewer 4:
The reviewer said this work improves U.S. technological ability to improve manufacturing of electrode materials for vehicle electrification.

Reviewer 5:
This reviewer cautioned that on the surface, the effort comes across as one which is more focused on manufacturing cost and not an approach which increases manufacturing sector capacity.

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

Reviewer 1:
The reviewer noted the collaborative laboratory team has access to a wide variety of tools and resources to support conduct of this effort.

Reviewer 2:
This reviewer concluded the resources were appropriate given budget limitations.

Reviewer 3:

The reviewer remarked this is a fairly expensive project, compared to others.

Presentation Number: es266
Presentation Title: Co-Extrusion (CoEx) for Cost Reduction of Advanced High-Energy-and-Power Battery Electrode Manufacturing
Principal Investigator: Ranjeet Rao (PARC)

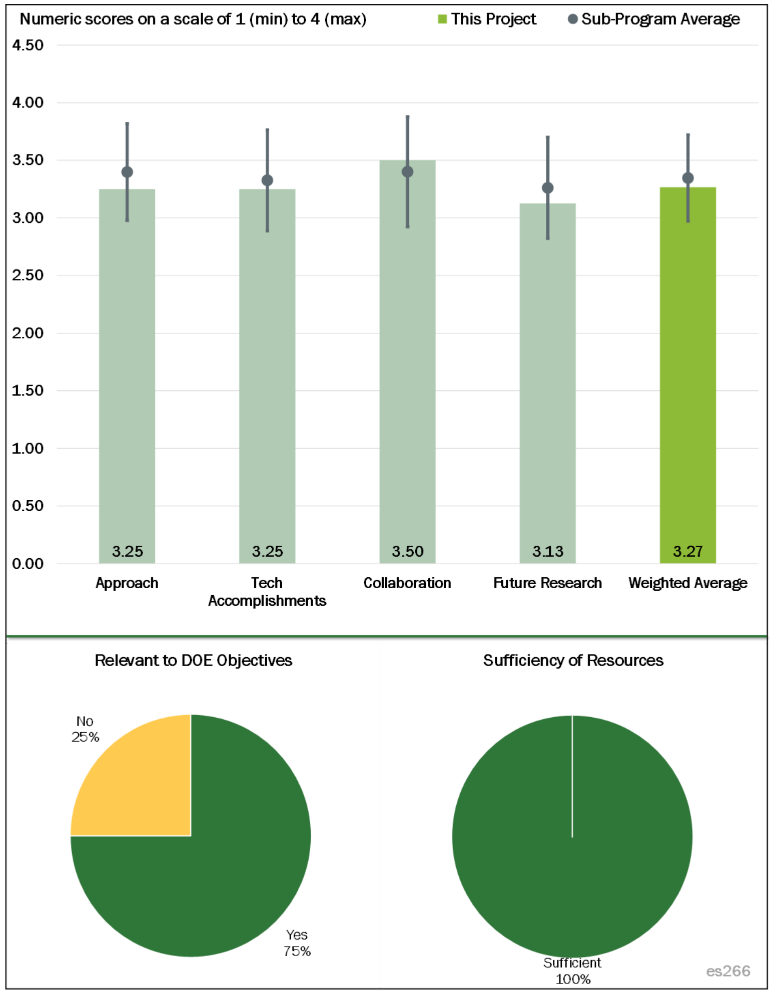

Figure 3-38 - Presentation Number: es266 Presentation Title: Co-Extrusion (CoEx) for Cost Reduction of Advanced High-Energy-and-Power Battery Electrode Manufacturing Principal Investigator: Ranjeet Rao (PARC)

Presenter

Ranjeet Rao, PARC

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

This reviewer was surprised to see calendered electrode still showed performance advantages of peaked electrode. The person was glad to see matching anode has been determined and that option 3 takes into account concerns for volumetric energy density penalties. The program seems to be making good progress.

Reviewer 2:

This reviewer acknowledged the approach of the project was to focus on a way to implement a concept that allows for the use of thick anodes and cathodes via a co-extrusion method. The process required work on binders and conductive additives. The reviewer commented that the technical goal of a thick crack free anode was clearly spelled out as well as the performance targets.

Reviewer 3:

This person said the approach to make a high-energy and high-power electrode via interdigitated design to increase surface area and thick electrode to increase energy density is very reasonable. The reviewer warned that regions of high porosity mixed with regions of low porosity in the interdigitated electrode will result in uneven current density and possibly lead to Li plating on the anode.

Reviewer 4:

This reviewer stated the research team is focused on process approaches to drawing/processing thick films of PVDF composite materials. As such, this work involves use of established thick-film process technology to support drawing LIB anodes/cathodes/etc. This person recognized that LIB materials sets represent relatively new application technology area for the selected process, but it needs be noted that analogous industries have been processing like-type films for a range of electronic applications for decades. The use of a “print-head” that is pressure-fed higher solids-loaded slurries to process thick-films is a logical casting, a reasonable approach, and should prove successful. Of course, as processing cost is a major objective for this project, the reviewer asserted cost-savings will only be had after volume manufacture and commercial scale-up. What is not presented is how this process approach creates a means to save significant process cost when compared to other continuous processing approaches, such as slot-die (single- or multiple-pass), etc. This person noted that casting thick-films of dielectrics and piezoelectrics at thickness at and greater than, for current commercial products is commonly accomplished employing similar approaches. In fact, PVDF is commonly used in large scale for piezoelectric applications. This reviewer hoped that common industry practices for these applications would have been studied in developing the overall statement of work for the project. Regardless, the reviewer concluded that there needs be a comprehensive TEA conducted to determine if this justifies federal investment.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This reviewer commented the project team co-extruded calendered electrode based on the corrugated electrode modeling design and demonstrated significant advantage over a conventional electrode with comparable thickness. The project team needs to address the internal short risks associated with loose foreign object damage particles from the co-extruded electrode. Based on the half-cell data, this reviewer mentioned the project team should provide cell level power density (W/L or W/kg) projections of their corrugated thick electrode.

Reviewer 2:

The reviewer commented the results presented relative to conventional cells show significant improvement with the process however, actual values would have been more helpful. The work on identifying a suitable anode to move forward with was excellent, and the demonstration of results in a 1 Ah full cell was good. It was not clear to this reviewer from the material presented however, if either or both the cathode and anode had been through the co-extrusion (CoEx) process for the cell, nor what the thickness was prior to calendering.

Reviewer 3:

This reviewer said materials have been successfully processed which have supported process into battery systems. Testing has demonstrated that the likelihood of success remains high and that regardless of achieving cost related objectives, the approach should enable near equivalent manufacture of assemblies with performance similar to current commercial approaches. This reviewer raised concerns regarding ultimate quality of cast films, especially as thicknesses are increased, that need to be more comprehensively addressed. In other industries, this is often an issue relating slurry solids loading, solvent selection and rheology. This person suggests that these variables be addressed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

This reviewer exclaimed the team put together for this project was excellent! It included an automotive original equipment manufacturer (OEM) and a battery supplier.

Reviewer 2:

This reviewer affirmed there was good collaboration and that the roles of each collaborator were specified.

Reviewer 3:

The reviewer observed the project team reports considerable interaction between PIs at Ford, PARC, and Navitas Systems, as well as with SMEs from other sectors.

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.

Reviewer 1:
This reviewer was very pleased to see plans for 14 Ah pouch cells. This seems like a real step toward being able to demonstrate functionality in the desired application.

Reviewer 2:
This reviewer agreed with the project team’s proposal to demonstrate the performance of co-extruded corrugated electrode in a full cell.

Reviewer 3:
The reviewer acknowledged that the proposed plans fit the initial goals, but appear to be behind schedule for the large format cell work. This person is not sure how the cost model estimates will be met based on model indications of a 10% improvement in energy density.

Reviewer 4:
This reviewer pointed out future efforts do need to address the topics presented in the poster “slide-deck.” However, beyond the items presented, as previously referenced, at this point a TEA should be accomplished in order to justify further federal investment. This person said tooling and “printing” or casting at scale will be part of the normal scale-up as industry moves to commercialize this approach.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
This reviewer mentioned that the project overall goal is to reduce the cost of this technology. This cost reduction fully supports the overall DOE objectives toward petroleum displacement.

Reviewer 2:
The reviewer remarked that assuming BatPac models are accurate, the project seems to provide some benefit without totally tearing up the existing cell manufacturing infrastructure.

Reviewer 3:
The reviewer said it is still not clear the feasibility of scaling up this technology but insights learned from corrugated electrode will guide future thick, high-energy electrode design.

Reviewer 4:
This reviewer noted that on the surface, the effort comes across as one which is more focused on manufacturing cost and not an approach which increases manufacturing sector capacity. Even if successful, this person warned this approach will likely only replace like-type manufacturing and not be cause to displace current petroleum use/needs.

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

Reviewer 1:
This reviewer stated $2.99 million for about 40 months should be sufficient to demonstrate full cell performance using their co-extruded corrugated electrodes.

Reviewer 2:
The reviewer concluded the funding is sufficient for this project.

Reviewer 3:

The reviewer observed the collaborative lab project team has access to a wide variety of tools and resources to support conduct of this effort.

Presentation Number: es267
Presentation Title: Commercially Scalable Process to Fabricate Porous Silicon
Principal Investigator: Peter Aurora (Navitas Systems)

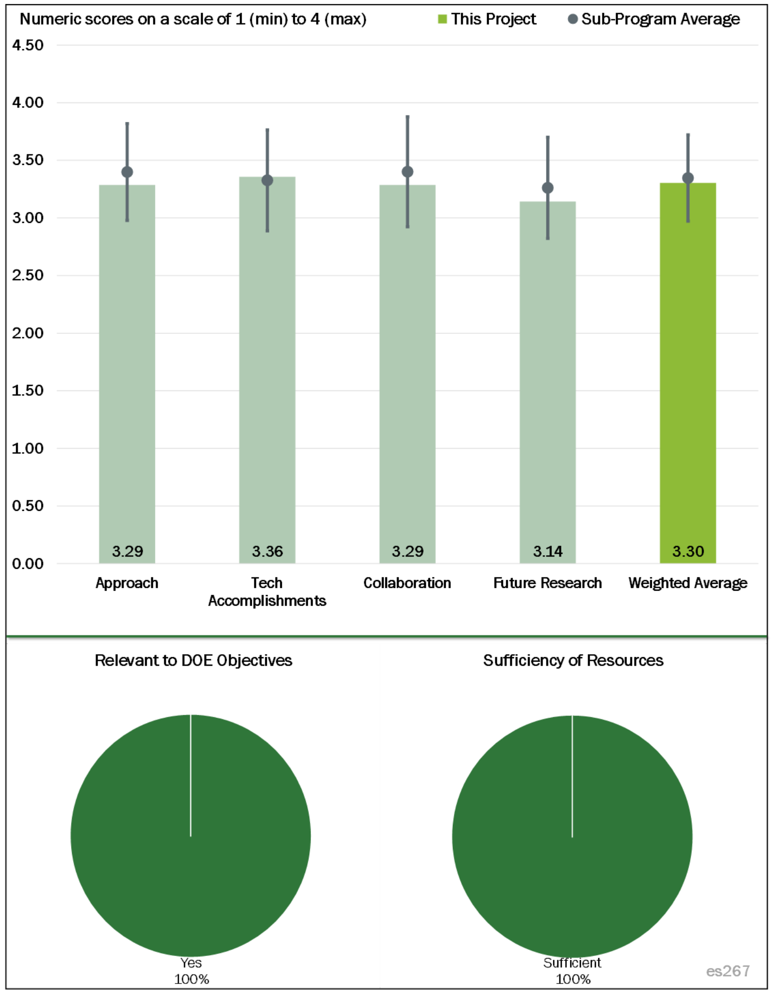

Figure 3-39 - Presentation Number: es267 Presentation Title: Commercially Scalable Process to Fabricate Porous Silicon Principal Investigator: Peter Aurora (Navitas Systems)

Presenter

Peter Aurora, Navitas Systems

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer remarked that the project is well-designed to achieve low-cost and less environmental footprint.

Reviewer 2:

The reviewer said that primary program objectives appear to have been met.

Reviewer 3:

The reviewer said that the approach to technology development, and partnering for scale-up, seems sound.

Reviewer 4:

The reviewer pointed out a low-cost process to produce Si.

Reviewer 5:

The reviewer asked what the reducing metal used in Step 1 is, and what the etching agent is if hydrofluoric acid is not used.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:

The reviewer said that scale-up of processes appears to be going well and milestones are completed. Projected cost is comparable to graphite (per unit of capacity). The reviewer said that this technology appears to be about as good as can currently be achieved with “standard Si.”

Reviewer 2:

The reviewer said that significant progress has been made on scale-up.

Reviewer 3:
The reviewer commented improvement of the Si to be test at full cell and also the evaluation of volumic expansion.

Reviewer 4:
This reviewer indicated an inability to evaluate the cost analysis without knowing the types of reducing metals and the etching agent used in the process.

Reviewer 5:
The reviewer asked if there were any issues with ultra-fine Si nanoparticles that are likely created in this process. The reviewer inquired if the Si particle size can be reduced, and what the optimal size is. The reviewer indicated that cell data look okay but not spectacular.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer pointed out great collaboration with ANL.

Reviewer 2:
The reviewer said that the team might need the collaboration with battery manufactures in order to make better pouch cells and for future commercialization.

Reviewer 3:
The reviewer said none.

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.

Reviewer 1:
The reviewer said that the future plan is reasonable and practical.

Reviewer 2:
The reviewer is very curious to see a validated cost model, and would expect the cost of reducing metal to be expensive. The reviewer understood that the developer did not want to share the material, but it seems like costs could be a risk.

Reviewer 3:
The reviewer said that the project is very near completion, and the reviewer would like to see more concrete ideas for how Nexceris or another partner will commercialize the product after funding is ended.

Reviewer 4:
None were noted by this reviewer.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said that this work improves U.S. technological ability to improve manufacturing of electrode materials for vehicle electrification.

Reviewer 2:
The reviewer cited a low-cost and environmentally friendly process.

Reviewer 3:
None were noted by this reviewer.

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

Reviewer 1:
The reviewer said that resources seem well-used on this project.

Reviewer 2:
None were noted by this reviewer.

Presentation Number: es268
Presentation Title: Low-Cost Manufacturing of Advanced Silicon-Based Anode Materials
Principal Investigator: Aaron Feaver (Group 14 Technologies)

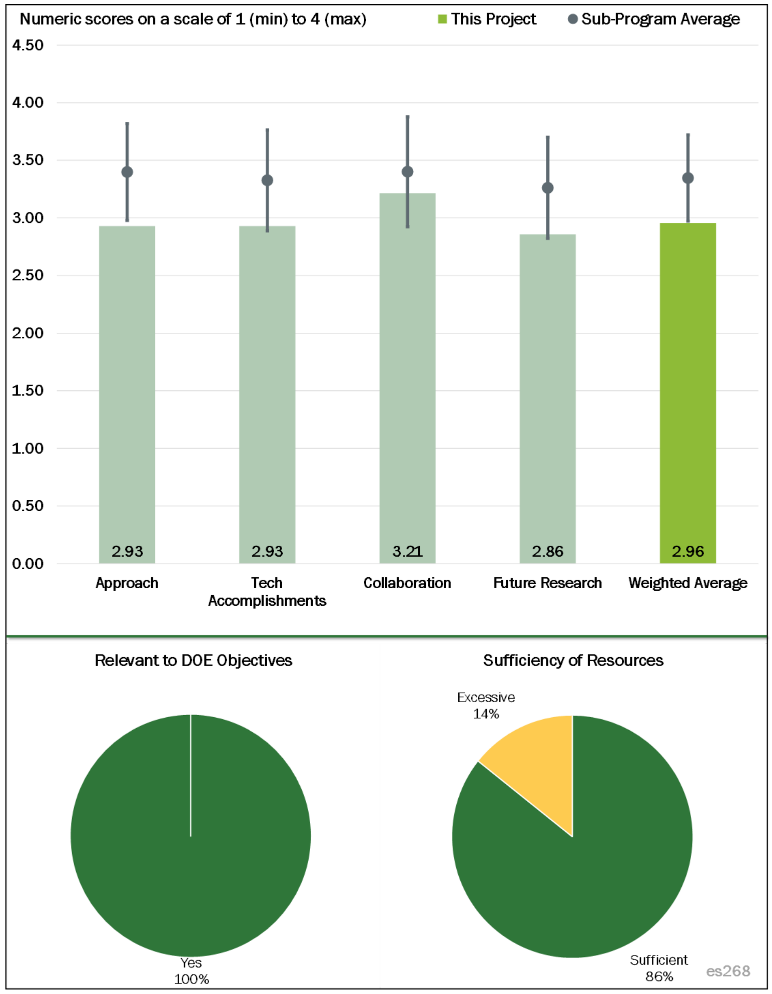

Figure 3-40 - Presentation Number: es268 Presentation Title: Low-Cost Manufacturing of Advanced Silicon-Based Anode Materials Principal Investigator: Aaron Feaver (Group 14 Technologies)

Presenter
Henry Costantino, Group 14 Technologies

Reviewer Sample Size
A total of seven reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer said that the team is currently pursuing the only sensible approach to using Si: putting it in some kind of matrix that minimizes detrimental effects of volume changes and allows for electronic contact. The team also has paid a lot of attention to how their technology can be scaled to kilogram quantities.

Reviewer 2:
The reviewer noted that the project is developing a carbon (C)-Si composite anode to increase capacity relevant to C while addressing the limited cyclability of Si. The reviewer pointed out that many groups are doing this and the approach to develop this composite was not described so it was hard to give any score on the uniqueness of approach.

Reviewer 3:
The reviewer detailed that the approach is to reduce cost by increasing energy density via SiC anode. Milestones and go/no-go decision points were specific and quantifiable.

Citing proprietary information, the project team would not disclose how the Si was supported on the C matrix, and would not disclose the synthesis process or the precursors used in the synthesis, thus it is very difficult to assess the feasibility of achieving the $125/kWh cost target.

Reviewer 4:
The reviewer said that the program claims to show cycle stability to 600 cycles, but the data appear to show that all of the Si composite anodes are at the same energy density as a standard graphite anode after 500 cycles, and the trend line continues to point downward at a more rapid rate than for graphite only. The reviewer interpreted this to mean that the Si does not appear to be stabilizing in any way and the only stabilizing

component is the graphite itself. If the new technology is at parity with state-of-the-art technology halfway through the cycling target, and projected to be worse over the second half of the life target, the reviewer did not see a technological advantage to the material.

The reviewer said that the developer has also not done a very good job of explaining the distinguishing trait that leads to the novel aspect of their material other than "low two-dimensional expansion," which the reviewer does not have anything to compare their measurement to for other Si materials. The reviewer is sure 30% is still more significant than graphite, and because a physical lithiation took place instead of an electrochemical lithiation the reviewer is not sure it is showing the full expansion of the material. The reviewer thought a lot of the development of Si anodes should be focused on electrolyte-anode pairing and stable SEI formation; it seems unlikely that this material will meet end of program 1,000 cycle goals using an off-the-shelf electrolyte formulation (and the reviewer understands this is likely outside the scope of this program).

Reviewer 5:

The reviewer said none.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:

The reviewer remarked that the use of novel C materials seems unique.

Reviewer 2:

The reviewer commented that the project does seem to show improvement over the beginning of program performance, but the reviewer was still unclear if this actually provides a benefit if energy density at 500 cycles is equal to graphite.

Reviewer 3:

The reviewer noted that the team has made SiC composites with increased capacity relative to C, and of course less capacity than Si. TEM results indicate significantly reduced expansion issues relative to Si. However, capacity fade is still significant.

Reviewer 4:

The reviewer said that coin cell data appear quite good; however, the reviewer would like to see more than "one or two" good cells before the team proceeds with process scale-up. The reviewer said that confidence for that kind of investment requires a presentation of a lot more repeated tests. The team's use of micron-scale aggregates indicates the team has a good idea of what industry needs to make this a product that can drop into existing processes. The projected price is comparable to graphite per mAh.

Reviewer 5:

The reviewer pointed out that the project achieved a pilot scale 10g synthesis of the Si/C mix and demonstrated greater than 300 cycles in full cells with energy density greater than 700 Wh/L at C/2 rate.

The energy density was very high, close to 800 Wh/L at 4.2V 2.5V at a C/10 rate. The reviewer said that the team needs to provide enough details on the cell modeling (e.g., loading, specific capacity of the Si/C composite, porosity, first cycle irreversible loss) to show how they achieved 800 Wh/L at only 4.2V.

Reviewer 6:

The reviewer acknowledged having not seen the capacity mAh/g versus cycle, energy density Wh/k, the loading, irreversible capacity, etc. The *in situ* TEM should be with an anode (Si-binder) and no one particle.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that strong collaboration with PNNL was demonstrated.

Reviewer 2:
The reviewer commented that the PNNL analysis of materials is excellent and convincing. The reviewer would like to see more cycling and cell test data, perhaps by partnering with a group able to do that.

Reviewer 3:
The reviewer noted good collaboration with PNNL and the University of Washington, with sufficient details on the role of each team member.

Reviewer 4:
None were observed by 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.

Reviewer 1:
In addition to the future focus on scaling up, the team needs to include a third-party to perform independent validation of the excellent density achieved at 4.2V.

Reviewer 2:
The reviewer said that proposed future work is good, but the team needs to address capacity fade and also update cost analysis.

Reviewer 3:
The reviewer said that a kilogram scale is probably needed to confirm larger cell format cycle life performance, but the reviewer was not convinced that cell performance at this time justifies cost investment in process scale-up.

Reviewer 4:
The reviewer said that as mentioned in previous comments, the team needs to consider more than just process scale-up. However, process-scale-up plans themselves are adequate.

Reviewer 5:
None were cited by this reviewer.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer pointed out that improved batteries will advance vehicle electrification and thus displace petroleum.

Reviewer 2:
The reviewer said that using a high-energy and inexpensive anode is relevant to achieving DOE’s EV objectives.

Reviewer 3:
The reviewer commented that this work improves the U.S.'s technological ability to improve manufacturing of electrode materials for vehicle electrification.

Reviewer 4:
The reviewer said yes, assuming program goals are met.

Reviewer 5:
The reviewer said none.

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 appear adequate.

Reviewer 2:
The reviewer said that $2.8 million for 3 years is sufficient to demonstrate the performance and scalability of the SiC composite.

Reviewer 3:
The reviewer said that the budget seems high relative to other projects evaluated.

Reviewer 4:
The reviewer had no comment.

Presentation Number: es269
Presentation Title: An Integrated Flame Spray Process for Low-Cost Production of Battery Materials
Principal Investigator: Yangchuan Xing (University of Missouri)

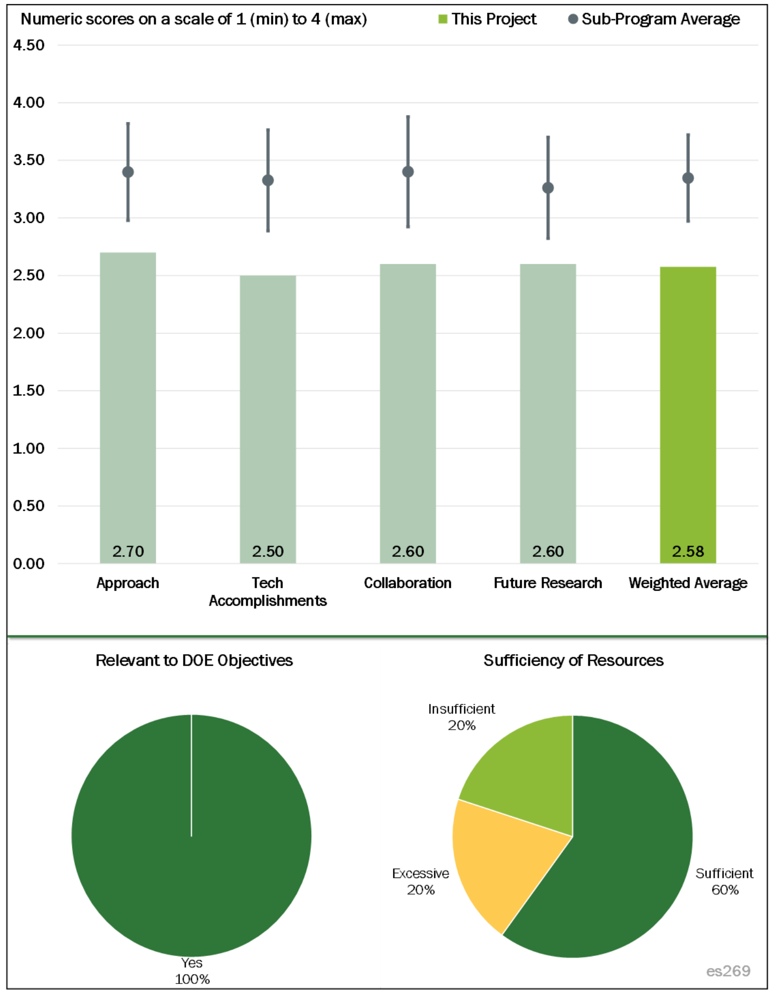

Figure 3-41 - Presentation Number: es269 Presentation Title: An Integrated Flame Spray Process for Low-Cost Production of Battery Materials Principal Investigator: Yangchuan Xing (University of Missouri)

Presenter

Yangchuan Xing, University of Missouri

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that the approach taken to reduce manufacturing cost is good. Replacing water with biomass glycerol would save on water treatment cost.

Reviewer 2:

The reviewer said that the integrated flame spray process has potential to reduce cathode powder cost by process intensification. However, this aspect (process intensification and reduced cost) is not demonstrated yet. The reviewer pointed out that the figure on Slide 6 is a schematic of coated powder production, but where is the coating process described or shown. Also, current significant Li loss will impact cost.

Reviewer 3:

The reviewer said that although the process could be a sustainable material manufacturing process, how to scale-up and achieve better quality control could be issues in the future.

Reviewer 4:

The reviewer said that the process path selected seems to be a reasonable approach to fabricating powder systems for use in LIB systems. It presents a means to insure compositional homogeneity and purity in processed materials. Selected chemical precursors can be readily and fairly easily blended so as to achieve most chemistries envisioned to be of use for these systems. The reviewer noted that process tooling is near-commercially available and can be modified, as can most process condition variables to meet the unique needs to achieve high volume of spherical particles. The reviewer pointed out that what appears absent from the approach and work-plan includes: a means to fully classify finished powders to specified particle size diameters (PSD), a viable means to ALD coat as-finished powders while surfaces remain chemically active and receptive to any required coating as poster/slide-deck over-simplifies this process step, development of a roadmap and techno-economic analysis to determine if approach is commercially feasible if objectives are achieved, etc.

Reviewer 5:

The reviewer said that major weaknesses in the approach are associated with scaling up the process to produce materials at lower cost than current prices. The poster provides no information to support the idea that flame spraying technology can be scaled-up to allow the production of several hundred tonnes of material per year without loss of uniformity and electrochemical performance. (The reviewer noted that in discussion, the presenter cited the fact that flame spraying technology is currently used to produce very large quantities of simple metallic oxides. But the materials cited contain a single metal and are used in pigments—a simpler structure used in a less demanding application.)

The reviewer said that in describing the reactants, the paper identifies that the solvent is “glycerol from biomass,” a byproduct of the production of biodiesel—implying that it is readily available, renewable, and inexpensive. But no data are given to support this implication. The reviewer remarked that the paper states that metal acetates are used in preparing the spray solution. One expects metal acetates to be significantly more expensive than the metal salts used in conventional production. The only Li-containing materials produced in sufficient quantities to supply the cathode industry are Li-carbonate and Li-hydroxide. Converting either of these to Li-acetate would add additional cost.

The reviewer pointed out that flame spraying would not allow the production of some of the materials now under development, such as core/shell materials. In the drawing on Slide 6, the presentation implies that flame spraying equipment would allow “coating” and “processing” of the materials in an integrated system; but there is no discussion as to what this system would be or how it would function.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:

The reviewer said that the effort continues to move in the right direction. This past year, a Generation 3.0 reactor was constructed and the team expects to meet the production rate goal.

Reviewer 2:

The reviewer noted that lower cost materials are certainly important in meeting DOE's cost goals. The goal of this project is “low-cost production of battery materials,” but the presentation provides no specific data to support this goal or the specific cost targets mentioned on Slide 3.

The reviewer said that to be accepted by the battery industry, materials must be shown to be consistent in composition, structure, and form (shape and density) over multiple, extended production runs. There are no data in the poster to show that the current process can produce consistent material during a single run, let alone over many runs.

The focus on Ni Mn Co oxide (NMC)111 and NCA may be an acceptable starting point, but neither of these materials are currently being considered for use in “next-generation” batteries for vehicles. The poster gives no information about how many production runs have been made or any discussion as to the issues with getting good materials from multiple runs.

Reviewer 3:

The reviewer said that the team has demonstrated progress in achieving what appears to be reasonably dense, fine grained particle aggregate of fairly uniform size. Work to demonstrate the final chemistry of these materials indicates a fair level of homogeneity, although extensive loss of Li from the chemistry was observed. The team indicates that the next phase will focus on “scale-up” and adjustments to current tooling sets. However, before this effort should begin, there are a number of unanswered questions which need to be addressed. According to the reviewer, these include: what particle densities are actually achieved; what yields are seen of spherical versus other "shaped" particles, i.e., SWARF, fines, and other debris; can loss of high vapor pressure materials be compensated for in the precursor chemistries without adversely impacting the process flow or final compositional homogeneity of finished powders; is there PSD control and can the processed powders be physically classified into specified PSDs, further will use of multi-model blending achieve enhanced packing densities in use; a discussion of actual raw materials costs and current state-of-the-art process approaches are needed; the approach to ALD or other-type coating, if any appears overly simplistic; etc.

Reviewer 4:

The reviewer said that the team has demonstrated the capability to make NMC powders at large volumetric rates, but the product has significant issues: particle size is not adequate, 21% Li loss in pyrolysis, and secondary phase formation. As a result, electrochemical performance was poor. The reviewer said that adding 30% excess Li improved, but that would be a significant increase in cost. The reviewer asked how this Li loss will be addressed.

Reviewer 5:

The reviewer said that electrochemical performance is not promising at this stage. The team should also compare with the commercial materials and identify the main factors responsible to the poor performance.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer said collaborating with EaglePicher.

Reviewer 2:

The reviewer stated that the team reports considerable interaction between PIs at Univ. of Missouri, EaglePicher Technologies, as well with potential subject matter experts from other sectors.

Reviewer 3:

The reviewer said that collaborative effort with EaglePicher Technologies is good. They have been a major supplier for military batteries and should be able to guide the PI on cell evaluations.

Reviewer 4:

The reviewer pointed out that except for mention of a partnership with EaglePicher for production of test cells, there does not seem to be any outside collaboration. The nature of this collaboration is not described. One might infer that it is a relatively arms-length relationship: The University delivers material to EaglePicher, which makes cells using their proprietary anode. The reviewer pointed out there is no mention of active collaboration or feedback from EaglePicher to the university.

The reviewer noted that EaglePicher is an established manufacturer of cells and batteries in multiple chemistries, but their market has traditionally be the military and related users. They do not have any significant business producing cells or batteries for production, passenger vehicles.

Reviewer 5:

The reviewer said that the team might explore some collaboration with the experts on cathode materials from national laboratories or universities.

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.

Reviewer 1:
The reviewer said that the PI appears to be aware of the challenges with developing a low-cost battery cathode production process. This coming year, the team will continue to optimize the powder morphology and the process control will be investigated. There will be focus on increasing the production rate.

Reviewer 2:
The reviewer said that the team suggests that work will now focus on scale-up, tooling and addressing chemistry concerns as a result of thermal processing. It seems that much more fundamental effort is first needed to address fully characterizing current state-of-the-projects and determining how to address chemistry issues and coating approaches. The reviewer said that the team should rethink milestone events and consider what new roadmaps, economic issues, process and property issues need first to be solved prior to moving ahead with future work.

Reviewer 3:
The reviewer commented that for the future plan, the team should focus on optimizing the process and achieve the comparable performance as the material synthesized from traditional wet chemistry.

Reviewer 4:
The reviewer noted Li loss, phase purity, and particle size/morphology are major issues and are not sufficiently addressed.

Reviewer 5:
The reviewer said that the list of proposed future work identifies tasks in very general language with little detail about what each of the tasks might involve or how they would be done.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer noted that lower-cost batteries will advance vehicle electrification and thus displace petroleum.

Reviewer 2:
The reviewer pointed out that one of the major factors in the battery cost is the cathode. Therefore, reducing the cathode materials cost should have a major effort in reducing battery cost and motivating the consumer to use EVs.

Reviewer 3:
The reviewer said that introduction of LIBs with the transportation sector will result in lightweighting of designed vehicles which serves to conserve energy, whether it be petroleum or other based energy source. However, this project is one which is focused on energy storage, regardless of generating source. However, if found to be economically viable in the commercial space, the approach would serve to enhance manufacturing capacity and thus serve to increase product availability, resulting in increased product available for EVs and other applications.

Reviewer 4:
The reviewer noted that because DOE is interested in reducing the costs of advanced batteries and because reducing the cost of component materials will help reach this goal, this project may be able to support the overall objectives.

The reviewer used the words “may support” rather than the words “will support” because little specific data are provided to support the assertion that this approach will be low-cost. Therefore, the answer of “Yes” to this question is a qualified assessment. The reviewer noted that if the options were other that “yes” or “no,” the reviewer would have chosen “maybe.”

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 it appears that there are sufficient resources for this project to achieve the proposed goals as planned.

Reviewer 2:
The reviewer noted that the collaborative Lab Team set has access to a wide variety of tools and resources to support conduct of this effort.

Reviewer 3:
The reviewer said that because the poster indicates that results have been obtained and the project is on schedule, one may infer that the resources are adequate. But the poster provides no information as to what facilities and equipment are available at the university, nor is there any discussion as to how many people are working on the project and what their backgrounds might be.

Reviewer 4:
The reviewer commented that collaboration with national laboratories and utilizing the advanced diagnostic tools might help the project and meet the milestones.

Reviewer 5:
The reviewer said that given budgets on other projects reviewed, this seems excessive for work involved.

Presentation Number: es271
Presentation Title: New Advanced Stable Electrolytes for High-Voltage Electrochemical Energy Storage
Principal Investigator: Peng Du (Silatronix)

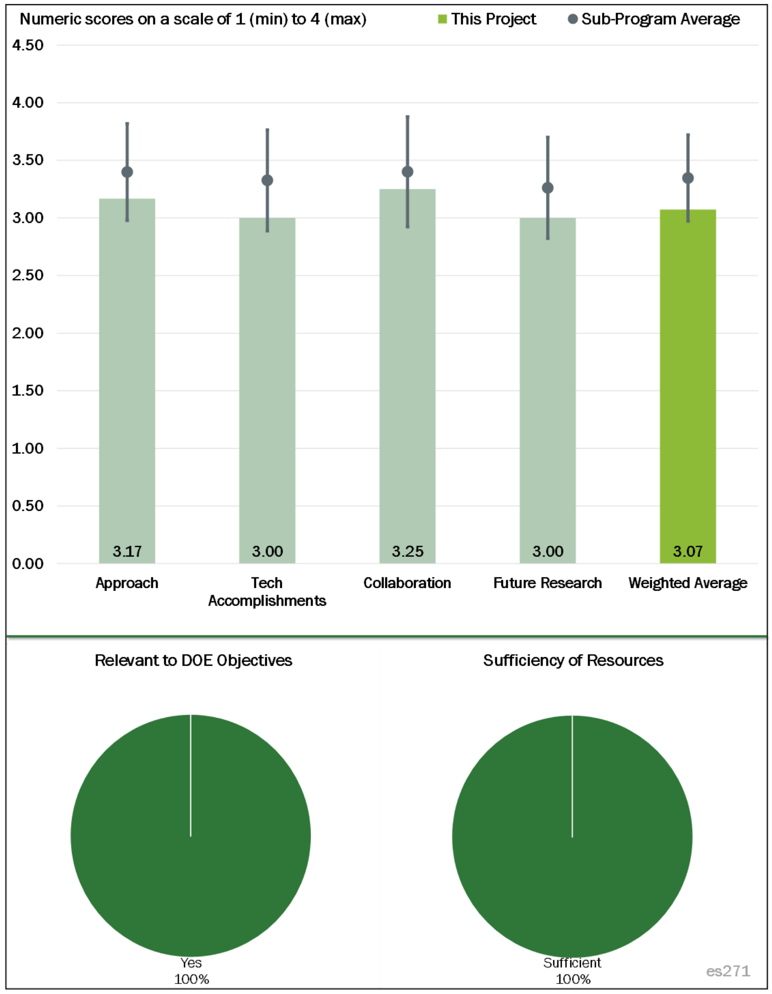

Figure 3-42 - Presentation Number: es271 Presentation Title: New Advanced Stable Electrolytes for High-Voltage Electrochemical Energy Storage Principal Investigator: Peng Du (Silatronix)

Presenter

Peng Du, Silatronix

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer commented that the approaches proposed are very unique and well-designed. If it is successful, it could significantly improve the energy density.

Reviewer 2:

The reviewer commented that the project has demonstrated an ability to synthesize high-voltage liquid electrolytes. The process has resulted in series of successful compositions which could have significant impact on battery performance.

Reviewer 3:

The reviewer observed a good approach by developing organosilicon (OS) solvents to stabilize Li-ion electrolytes for high-voltage cathodes. The milestones were specific and quantifiable go/no-go decision points. The use of spectroscopy methods (e.g., NMR) to characterize Li+ solvation behavior should be beneficial in developing and optimizing OS solvents.

The reviewer said that the team did not provide risks (e.g., compatibility with $LiPF_6$ electrolyte) and risk mitigation strategies. Some rationale should be provided on the downselection of the ARL additives.

Reviewer 4:

The reviewer noted that electrolyte for high-voltage helps increase the energy density when high-voltage cathodes are used.

Reviewer 5:

The reviewer said that the approach has resulted in mixed results. The goals for the pure OS materials in terms of high-voltage stability and leakage currents have been met by several formulations. The results for electrolytes containing OS components are much less positive. The reviewer said that to function as an effective electrolyte, only a small fraction of the mixture can be an OS. Cells built with these electrolytes do not seem to perform significantly better than cells using the best available control electrolyte. Cells built with the OS electrolytes have had limited testing because of a gassing problem.

Reviewer 6:
The reviewer stated that because all pouch cells are "showing a large amount of gassing," the project objective of developing "an electrolyte system stable at high-voltage (≥ 5V)" is unlikely achievable.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:
The reviewer pointed out that the demonstrated high-voltage capability is excellent, and asked but what is the conductivity. There is a table on Slide 8, but no units. The reviewer asked where the data are supporting these values. Also, gassing is an issue with safety implications that needs to be addressed.

Reviewer 2:
The reviewer noted that the team achieved impressive reduction in residual currents above 5V and voltage stability greater than 6V were demonstrated in half cells using the OS solvents in $LiPF_6$ electrolytes. The team also identified a gassing issue at greater than 4.7V.

The reviewer said that full cell results did not show the benefit of OS additives cycling at 55° C with 4.9V cut-off. Spectroscopy studies showed that OS solvents had high affinity for Li+ ions and should impact SEI formation but the impact was not evident in full cell results. The reviewer said that the ARL additives did not enhance the performance of OS3 in electrolytes.

Reviewer 3:
The reviewer said that significant progress has been made to develop a high-voltage electrolyte. The reviewer inquired can this OS3 be applied to general electrodes to improve safety as well. It looks as though high-voltage electrode materials with reliable electrochemical performance are not really available yet. The reviewer stated that the new electrolyte cannot be used even if the project is successful.

Reviewer 4:
The reviewer said that milestones are completed on schedule, though the problem of a large amount of gassing remains a challenge.

Reviewer 5:
The reviewer said that as noted in the response to question two: the performance of several "pure" OS materials (with appropriate salt) has met the goals of the project for these materials. The performance of electrolytes containing some OS does not seem to be significantly better than the best available electrolytes without OS. And the OS containing electrolytes may have problems with gassing. No data are given on low-temperature performance.

The reviewer remarked that given the performance of the OS-containing electrolytes, they do not seem to offer significant benefit in meeting DOE's goals for a high-voltage electrolyte to be used in high-voltage cells.

Reviewer 6:
The reviewer said that the PI should use Al or carbon to test the electrochemical windows at high-voltage.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that strong collaboration between the prime and ARL is demonstrated.

Reviewer 2:
The reviewer said that there seems to have been good collaboration with ANL and ARL. Each of the outside laboratories had specific tasks reflecting their specific expertise. The poster presentation clearly incorporates data from the partners as well as the prime contractor.

The reviewer noted that there was no collaboration with a battery manufacturer, but given the relatively basic technology readiness level of these materials and electrolytes, that is not a major weakness.

Reviewer 3:
The reviewer remarked that the team is very strong and has complimentary skill sets. The team can explore more collaboration with industry, which might have high-voltage electrode materials.

Reviewer 4:
The reviewer said that good collaboration with ARL and ANL, but the role of ANL was not specified.

Reviewer 5:
The reviewer said none.

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.

Reviewer 1:
The reviewer agreed with the team's focus on reducing the gassing issue, especially as a function of voltage cut-offs.

Reviewer 2:
The reviewer noted that the project is 90% complete, so future research is primarily demonstration of cell performance with developed electrolytes.

Reviewer 3:
The reviewer remarked the proposed future work is appropriate and necessary, but it seems to be quite extensive given that the project is 90% complete and will end in September. This reviewer's assessment: a good list of things that should be done, but questions as to if there are time and funding to do them all.

Reviewer 4:
The reviewer said that there is insufficient detail about what to do to solve the large amount of gassing problems aside from lowering the test voltage. The project objective of developing an electrolyte system stable at high-voltage (greater than or equal to 5V) is unlikely achievable.

Reviewer 5:
The reviewer said more coordination is needed under the DOE EERE program.

Reviewer 6:
The reviewer said none.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said that improved batteries will advance vehicle electrification and thus displace petroleum.

Reviewer 2:
The reviewer remarked that a stable electrolyte for high-voltage cathode is relevant to achieving DOE high-energy density goals.

Reviewer 3:
The reviewer said that the project can meet the high-energy density requirement if it succeeds.

Reviewer 4:
The reviewer said given that DOE's goals for advanced cells and batteries may/will require the use of a "high-voltage" electrochemical couple and given that a high-voltage electrolyte will be a necessary component of these cells, the goals of this project were supportive of DOE's overall objectives.

Given that the electrolytes that have been developed and tested in this project do not seem to perform significantly better than the best electrolytes without OS components, this project may not actually provide significant support to meeting DOE's objectives.

Reviewer 5:
The reviewer said none.

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

Reviewer 1:
The reviewer commented that $1.7 million for 2 years should be sufficient for this effort.

Reviewer 2:
The reviewer said that funding is consistent with other projects funded.

Reviewer 3:
The reviewer said that the three partners in this project each have appropriate facilities and staff to accomplish their parts for the project.

Given that many of the milestones for the project have been met, one may infer that resources have been adequate. The reviewer said as noted in response to earlier questions, there is significant "future work" proposed given that the project is 90% complete. The remaining resources (time and funding) may not be adequate to accomplish all of this work.

Reviewer 4:
The reviewer said none.

Presentation Number: es273
Presentation Title: Composite Electrolyte to Stabilize Metallic Lithium Anodes
Principal Investigator: Nancy Dudney (Oak Ridge National Laboratory)

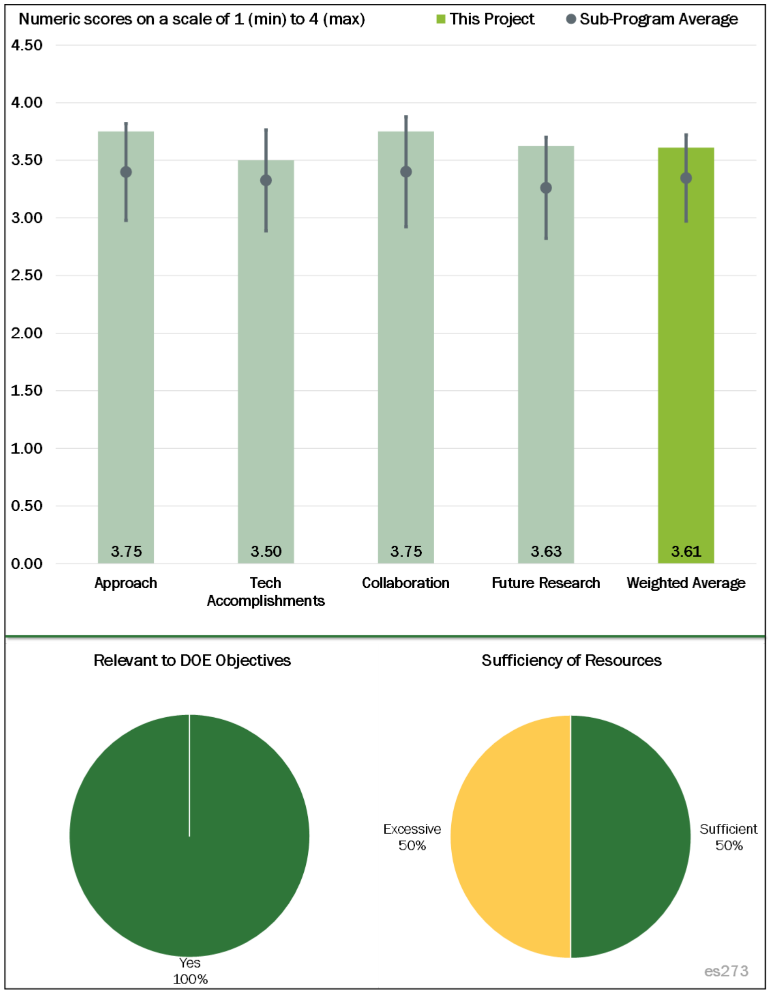

Figure 3-43 - Presentation Number: es273 Presentation Title: Composite Electrolyte to Stabilize Metallic Lithium Anodes Principal Investigator: Nancy Dudney (Oak Ridge National Laboratory)

Presenter

Nancy Dudney, Oak Ridge National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said, great work, the PI knows Li-metal very well and has a good approach. While the reviewer worried that composites will lead to current focusing and result in issues with dendrites, the reviewer fully supports this effort to see if this is indeed the case.

Reviewer 2:

The reviewer remarked that a composite electrolyte is one of the most promising directions to enable a Li anode. The spray-coating method is effective for the synthesis and is easy to scale up. The reviewer said the $Li_{2.88}PO_{3.86}N_{0.14}$ (LiPON) coating will be helpful to address the instability between the components and Li-metal anode.

Reviewer 3:

The reviewer observed a good approach in search for a Li dendrite blocking solid electrolyte. But, it appears as though the PI thinks the composite polymer electrolytes (CPE) will not stop dendrites, and therefore investigated a LiPON coating. This adds yet another interface with a relatively poor conducting solid, and the reviewer said it seems unlikely to work out.

Reviewer 4:

The reviewer said that a ceramic/polymer composite has many possible advantages in terms of blocking Li-dendrite growth, etc. The improvement in conductivity of such a composite, especially addressing interfacial resistance between two phases, remains a grand challenge for all the people working on this area.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:
The reviewer commented that the developed spray method using aqueous slurry is a great achievement. The reviewer is impressed by the mechanical strength of the LiPON layer coated on the CPE. The room temperature ionic conductivity is 10-5 S/centime (cm) only with the DMC vapor exposed CPE. The ionic conductivity without solvent still needs to be improved.

Reviewer 2:
The reviewer said good progress but very disappointing results. Poly(ethylene oxide) and Ohara glass are the two components of this composite electrolyte, both have room temperature conductivities that are too low for large format cells. The reviewer said that together, as a composite, they do worse, providing about 10^-6S/cm at room temperature, two orders of magnitude too low. This may be a consequence of the extra interfaces in this solid.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed reasonable good collaboration with academics and national laboratory groups.

Reviewer 2:
The reviewer said this project involves collaborations with both academic institution (Sakamoto at Michigan State University) and industry (Ohara).

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.

Reviewer 1:
The reviewer said that the future research is well planned: replacing Li aluminum titanium phosphate (LATP) with lithium lanthanum zironate (LLZO) may help to improve the interfacial stability and extra coating of LiPON may be not required. Using some improved polymer is the key to improve the ionic conductivity of the membrane. The reviewer said that a demonstration of a full cell from spray-coated method is encouraging.

Reviewer 2:
The reviewer noted reasonable as a research project, but this appears unlikely to yield a commercial solid electrolyte.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer commented that if successful, this project will enable Li-metal based batteries with very high energy density.

Reviewer 2:
The reviewer said very relevant but the results are not promising.

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 are sufficient to achieve the milestones, especially with the hiring of a polymer physicist and the in-house experiment with LLZO powder synthesis.

Reviewer 2:

The reviewer noted reasonable funding for the work being performed.

Presentation Number: es274
Presentation Title: Nanoscale Interfacial Engineering for Stable Lithium Metal Anodes
Principal Investigator: Yi Cui (Stanford University)

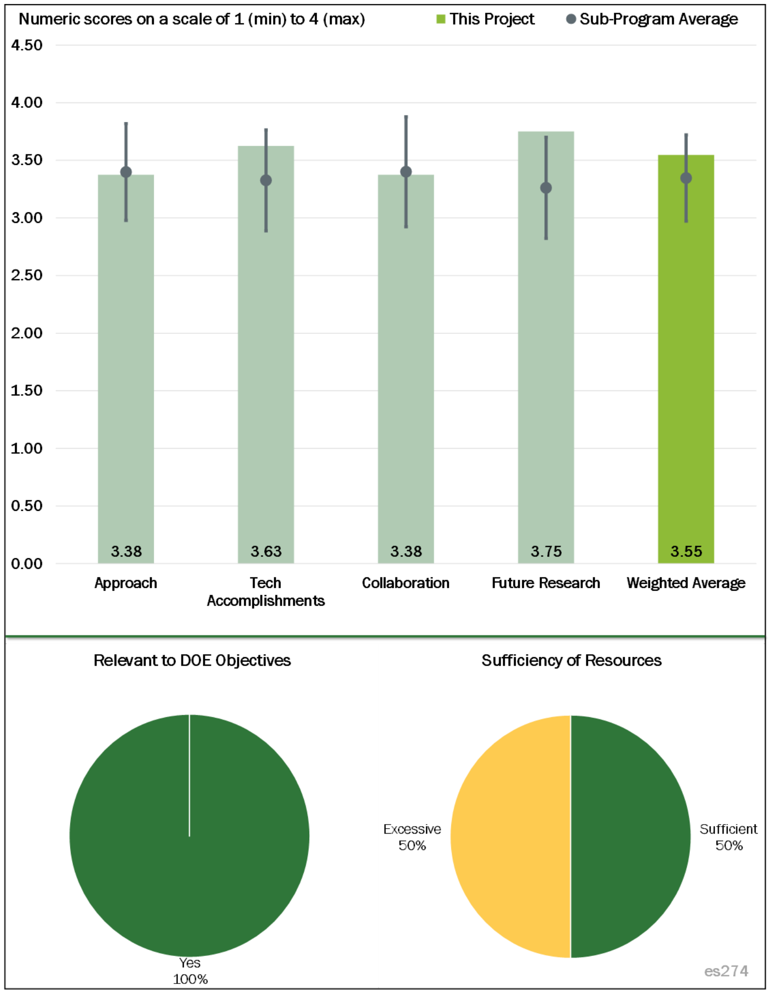

Figure 3-44 - Presentation Number: es274 Presentation Title: Nanoscale Interfacial Engineering for Stable Lithium Metal Anodes Principal Investigator: Yi Cui (Stanford University)

Presenter

Yi Cui, Stanford University

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that this work is always very inspiring. The work on changing the nucleation rates to ensure deposition in the shell was wonderful. The reviewer cited as a great example of the PI's creativity how the work on graphene seemed more hand waving in comparison. But overall, a great project.

Reviewer 2:

The reviewer remarked the project employed several very interesting and innovative approaches to address Li-dendrite growth issues.

Reviewer 3:

The reviewer commented that the PI clearly indicated the technical barriers of high-cost, low-energy density and short battery life for Li-metal batteries. The PI addressed these challenges by designing and synthesizing interfacial protecting layers and nanostructured Li-metal electrodes. The reviewer said that the advanced characterization technologies used in this research greatly enhanced the understanding of the mechanism.

Reviewer 4:

The reviewer said that reducing the volume change is a reasonable approach, but the reviewer is not convinced that electrode volume change is the major issue here. It is the instability at the electrolyte Li-metal interface and many of these methods are only partially able to reduce that interface. The reviewer pointed out that the increased wetting is critical and could reduce current focusing, which leads to dendrites.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:
The reviewer commented that results are outstanding. The team demonstrated significant improvement for performance and stability.

Reviewer 2:
The reviewer said that the PI improved the Li-metal cycling stability and CE by coating a composite layer/polymer on the Li-metal and greatly improved the cycling performance and CE. It should be a good progress toward the Li -metal batteries.

Reviewer 3:
The reviewer said accomplishments were mixed, and commented this approach still results in a rather low CE of 98%, meaning that the electrolyte/Li-metal interaction is still strong. As the goal is to cycle Li-metal cells with no more than 50% excess Li, these efficiencies are insufficient. This approach does appear to have reduced the likelihood of dendrite formation, which is excellent and a big step forward. The reviewer was not 100% clear how the self-healing polymer will stop dendrites if its stiffness is insufficient in the first place.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that all of the PI's coordination and collaborations are among the top, which improved the quality of the work.

Reviewer 2:
The reviewer remarked that the team has demonstrated extensive collaborations with co-PIs and industrial partners.

Reviewer 3:
The reviewer said that collaboration is relatively minor, which is appropriate for such early stage 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.

Reviewer 1:
The reviewer commented that proposed future research is very well thought out, and good recognition of the criticality of CE.

Reviewer 2:
The reviewer said that all of the proposed future research topics, including the improvement of the CE, and stable cycling stability at high-current density, are the key issues remaining for the Li-metal batteries.

Reviewer 3:
The reviewer said that the future research plan is reasonable. How to incorporate the innovative technical approaches into mass production of Li-metal anodes in a cost-effective manor remain as major challenges.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer remarked nice to see somewhat novel approaches attempted to dealing with Li deposition and dendrite issues. This is very relevant to all Beyond Li-Ion work, which is a growing portion of the VTO Energy Storage R&D budget.

Reviewer 2:

The reviewer said that the growth of the global EV market has been slower than initially predicted about 5 years ago due to the slow increase of the battery's energy density. Further increasing the energy density with long cycle life are the pivotal directions of the developments in LIBs.

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

No comments were received in response to this question.

Presentation Number: es275
Presentation Title: Lithium Dendrite Prevention for Lithium-Ion Batteries
Principal Investigator: Wu Xu (Pacific Northwest National Laboratory)

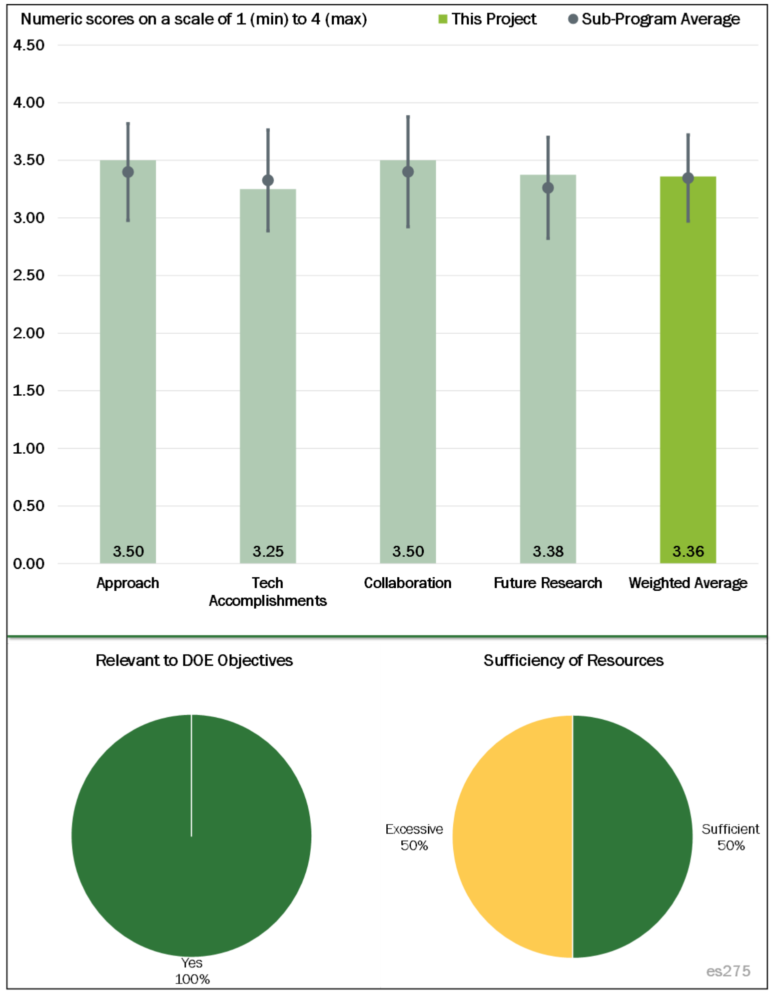

Figure 3-45 – Presentation Number: es275 Presentation Title: Lithium Dendrite Prevention for Lithium-Ion Batteries Principal Investigator: Wu Xu (Pacific Northwest National Laboratory)

Presenter

Wu Xu, Pacific Northwest National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that the PI clearly indicated the technological barriers of Li dendrite formation on Li-metal anodes in Li-metal batteries and on carbon anodes in LIBs. The PI addressed these challenges by designing a reasonable charge-discharge protocol for Li-metal electrodes. The PI also explored various factors that affect the morphology of Li deposition. The reviewer said that the advanced characterization technologies used in this research greatly enhanced the understanding of the mechanism.

Reviewer 2:

The reviewer remarked that compared with other approaches, such as coatings, artificial SEIs, etc., electrolyte modification and additives offer great potential to address several key concerns in Li-anode, but this has not been extensively explored. This project is addressing such an issue and the approach is industrially viable.

Reviewer 3:

The reviewer said a good approach to investigate new electrolytes and electrolyte additives to stabilize the Li-metal SEI.

Reviewer 4:

The reviewer expressed worry that the project is not recognizing that with so much excess Li, one can easily fool oneself into thinking that cycle life is not an issue. The reviewer recommended using thin Li, and making sure that the cells are truly Li limited. It will be best for the community to see which ideas are working versus not, rather than fooling ourselves into thinking it is all fine.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:

The reviewer remarked that the results are a great improvement of Li-corrosion protection and reducing dendrite growth.

Reviewer 2:

The reviewer said that the PI developed mixed salt electrolytes to protect Al current collector and Li-metal anode, and meanwhile achieved the Li CE over 98%. These achievements are great progresses for the Li-metal batteries. Besides, the Li||Li-iron phosphate ($LiFePO_4$) cells with 300 cycles is also a great progress for the Li-metal batteries.

Reviewer 3:

The reviewer would ask the PI to not show reviewers results involving additive “X”. The reviewer did not see any value in that. The $LiPF_6$ as an additive is interesting and shows promise. The reviewer would ask the PI to report how much Li is being cycled each cycle. If we are only moving 1% of the Li-metal anode on each cycle, then we already know we can cycle that thousands of times. If 50% of the Li is moved, then it has got a much, much shorter cycle life. As the PI is cycling Li-metal/NMC, the PI is technically not cycling any of the initial Li so it is really hard to say if this is significant or not. The reviewer believed the PI said the amount of Li was between 120 and 400 μ, or 24-80 mAh/cm^2. With the cathode at 1.5 mAh/cm^2, this is a massive amount of excess Li and the reviewer questioned the significance of the cycle life. The CE of 96% is low. If we start with 50% excess Li, the cell will be dead in 20 cycles.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer commented that all of the PI's partners are the top institutions of battery research. This collaboration and coordination can substantially improve the accomplishments.

Reviewer 2:

The reviewer said that collaboration is minimal but appropriate at this point in 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.

Reviewer 1:

The reviewer remarked that the PI proposed three future research topics; all of these topics are the key issues which should be overcome for the future commercialization of the Li-metal batteries.

Reviewer 2:

The reviewer said that proposed future research is reasonable, and the reviewer would encourage the PI to cycle cells with the least amount of Li-metal possible.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer stated that the growth of the global EV market has been slower than initially predicted about five years ago due to the slow increase of the battery’s energy density. Further increasing the energy density with long cycle life are the pivotal directions of developments in LIBs

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

No comments were received in response to this question.

Presentation Number: es276
Presentation Title: Mechanical Properties at the Protected Lithium Interface
Principal Investigator: Nancy Dudney (Oak Ridge National Laboratory)

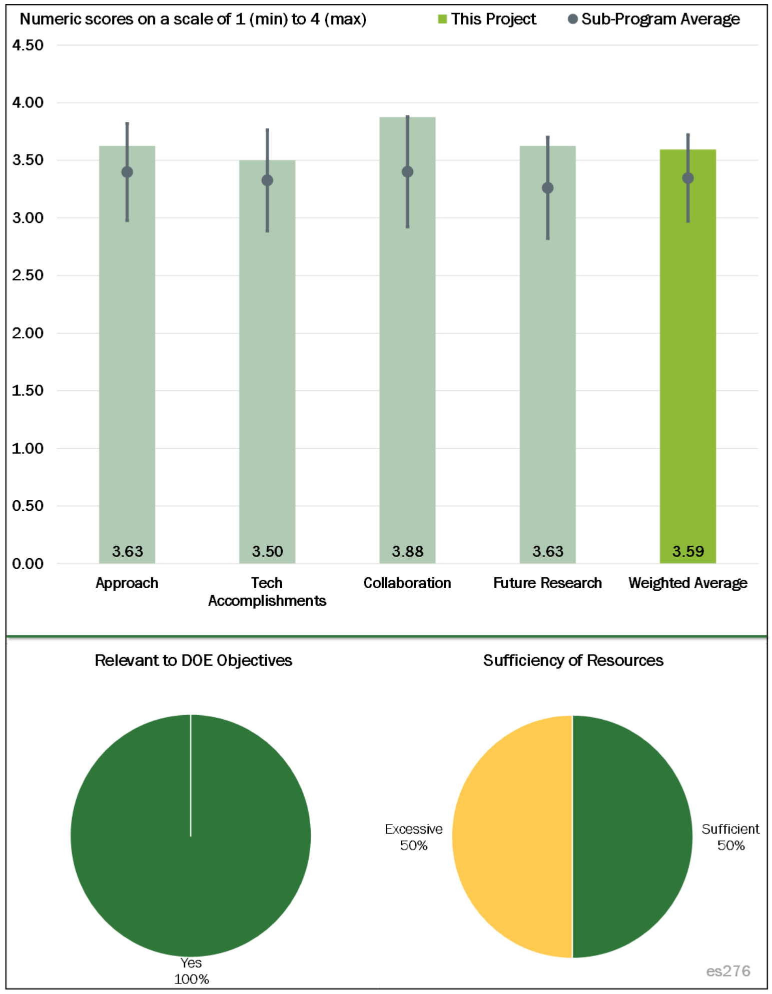

Figure 3-46 - Presentation Number: es276 Presentation Title: Mechanical Properties at the Protected Lithium Interface Principal Investigator: Nancy Dudney (Oak Ridge National Laboratory)

Presenter

Nancy Dudney, Oak Ridge National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that understanding the mechanical property of the Li/SEI is important to enable high-capacity Li-metal for a high-energy battery. Nanoindentation could provide much information about this.

Reviewer 2:

The reviewer said that the use of mechanical testing to probe Li-metal and the Li-metal SEI is a good addition to our existing electrochemical testing approaches. It will be extremely challenging to learn more about the SEI this way, but it is worthwhile.

Reviewer 3:

The reviewer commented that the project, as expected from the PI, is very relevant and focused. The work is really addressing the critical questions in Li-metal focusing on the interface. The reviewer was a bit concerned that the experiments were going after a microscopic quantity, while the issue is macroscopic in nature. Relating the two is going to be an issue. But, one has to start somewhere.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:

The reviewer said that the mechanical properties of thick Li anode has been studied, which will help to understand the deformations during Li plating and striping. The mechanical behavior inside the grain and around the grain boundaries could help to understand the dendrite formation mechanisms.

Reviewer 2:

The reviewer liked that the team broadened their approach to characterizing Li mechanical properties after the nanoindentation technique proved more difficult than expected. The relatively recent finding that dendrites grow through LLZO grain boundaries (Sakamoto) makes this project even more daunting. It is hard to imagine that we will find mechanical signatures of such small features. Still, according to the reviewer, this is worth pursuing.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer said very good collaboration with academia and industry, very complete team.

Reviewer 2:

The reviewer commented that this project involved close collaborations with academic institutions 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.

Reviewer 1:

The reviewer observed very solid future research, which includes further development of the technique and an attempt to detect defects in the solid electrolytes that impact Li dendrite growth.

Reviewer 2:

The reviewer said study of the mechanical behavior of Li and Li/electrolyte interface during cycling at different currents (or different strain rate) is of high interest and can provide many insights for further improvements.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer commented that understanding the interface between Li and solid electrolyte is one of the keys to enable a high-energy battery based on a Li anode.

Reviewer 2:

The reviewer said the project is highly relevant, but it must show an ability to repeatedly detect features that impact dendrite growth in the near future.

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

Reviewer 1:

The reviewer noted a very high budget, but with a good amount of work being done.

Reviewer 2:

The reviewer said that the resources are more than sufficient to achieve the stated milestones.

Presentation Number: es277
Presentation Title: Solid Electrolytes for Solid-State and Lithium-Sulfur Batteries
Principal Investigator: Jeff Sakamoto (University of Michigan)

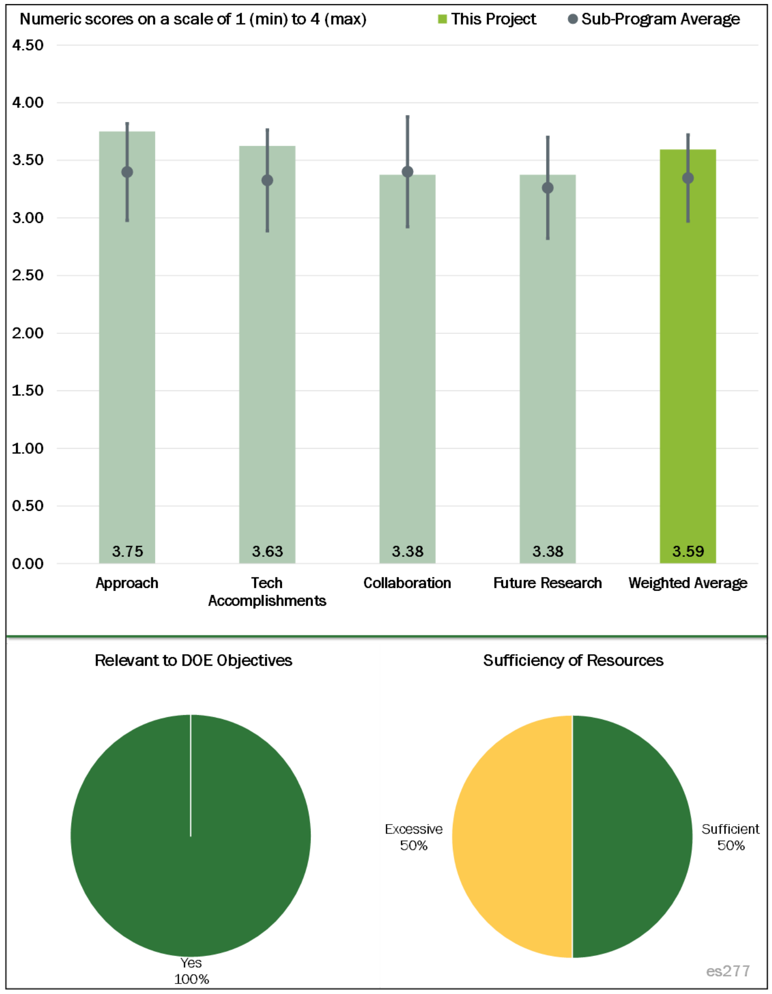

Figure 3-47 - Presentation Number: es277 Presentation Title: Solid Electrolytes for Solid-State and Lithium-Sulfur Batteries Principal Investigator: Jeff Sakamoto (University of Michigan)

Presenter
Jeff Sakamoto, University of Michigan

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented excellent project with a very good approach. The PI has shown the main failure modes for ceramics and leads the world in this area.

Reviewer 2:
The reviewer said very nice testing and diagnostics approach, and liked that the focus is on surface effects.

Reviewer 3:
The reviewer said that solid electrolytes are critical to suppress the dendrite formation and will also help to prevent the shuttle effect in Li-S batteries.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:
The reviewer commented that it is good that defects include the Li-LLZO interface, which is where the large impedance originates and grows during cycling. There seems to be growing consensus that poor Li wetting is the root of the high interfacial impedance.

Reviewer 2:
The reviewer remarked that the factors for the dendrite formation in LLZO has been systematically studied, from the porosity, to grain boundaries, and then to surface contaminations. The interfacial resistance has been reduced to 2 ohm/cm^2, which is much lower than that in the liquid electrolyte or LiPON-based Li cells. However, even with this low interfacial resistance, the critical current density (CCD) is still much less than 1 mA/cm^2. The reviewer said that other reasons need to be clarified.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer observed good collaboration, and liked that Ford is included in list of advisors/collaborators.

Reviewer 2:

The reviewer said that the project involved many collaborations from both national laboratories 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.

Reviewer 1:

The reviewer liked that the work continues to focus on the "why" of solid state battery interfacial impedance.

Reviewer 2:

The origin of Li dendrite formation in LLZO is still unclear, limiting a great improvement of CCD. The reviewer suggested more efforts towards this direction.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer said that if this succeeds, solid electrolytes will enable high-energy batteries with a Li-metal anode.

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 good amount of work for the funding provided.

Reviewer 2:

The reviewer said that the resources are sufficient for this project.

Presentation Number: es278
Presentation Title: Overcoming Interfacial Impedance in Solid State Batteries
Principal Investigator: Eric Wachsman (University of Maryland)

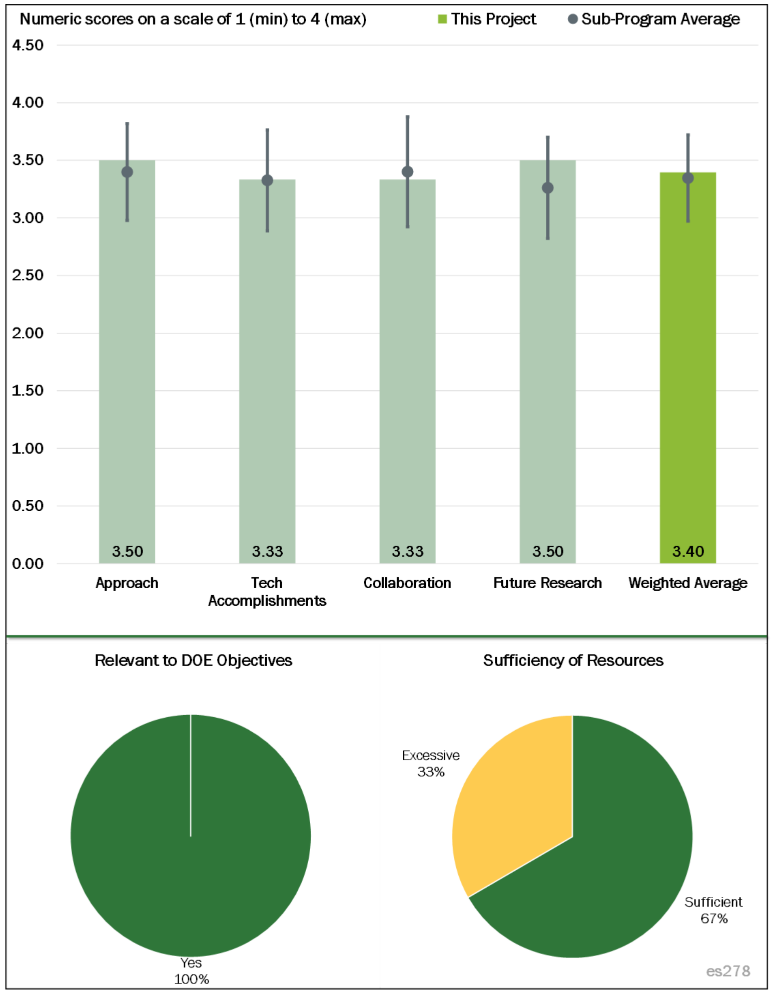

Figure 3-48 - Presentation Number: es278 Presentation Title: Overcoming Interfacial Impedance in Solid State Batteries Principal Investigator: Eric Wachsman (University of Maryland)

Presenter

Eric Wachsman, University of Maryland

Reviewer Sample Size

A total of three reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer remarked that this is one of the early demonstrations of the solid state battery after the work in Japan. The reviewer said really excellent work.

Reviewer 2:

The reviewer said that the project is focused on interfacial impedance, which is appropriate when researching solid state batteries. It seems likely that very high interfacial impedance, caused partially by poor contact between Li and the solid electrolyte, could be at least partially responsible for Li dendrite growth. But, according to this reviewer, Li dendrites also grow in cells with liquid electrolytes and with gel polymer electrolytes. So this “solution,” to improve the interface, is only a partial solution.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:

The reviewer observed good results, and believed the conclusions of this project are similar to or identical to the Sakamoto project, which is encouraging. The result is that Li-carbonate is at least partially responsible for poor interfacial impedance. Also, the finding that increased interfacial surface area can and does reduce impedance is expected but critical to show. The reviewer was somewhat surprised that full-cell Li/NMC cycling is shown only out to 15 cycles, and Li/S out to 30 cycles, which implies that there is a major issue out there. It would be nice if the PI told reviewers what that was. The CE of the Li/NMC full cells appears to be rather low, well under 99%. The reviewer asked does the PI know what the cause of this is.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

Considering the claims being made by this PI, the reviewer would encourage him to reach to battery or material developers for collaborative efforts on validation of his findings. Enabling solid state batteries remains the holy grail of battery R&D and should be pushed to commercialization.

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.

Reviewer 1:

The reviewer expressed surprised that future work does not include collaboration and validation with cell and material developers. The reviewer is also curious about the wide variation in interfacial impedance that were measured using different ALD surface treatments.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

No comments were received in response to this question.

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 this project had a reasonably high budget for a university project, but considerable work is being done as well, so appropriate.

Presentation Number: es288
Presentation Title: Construction of High-Energy Density Batteries
Principal Investigator: Christopher Lang (Physical Sciences Inc.)

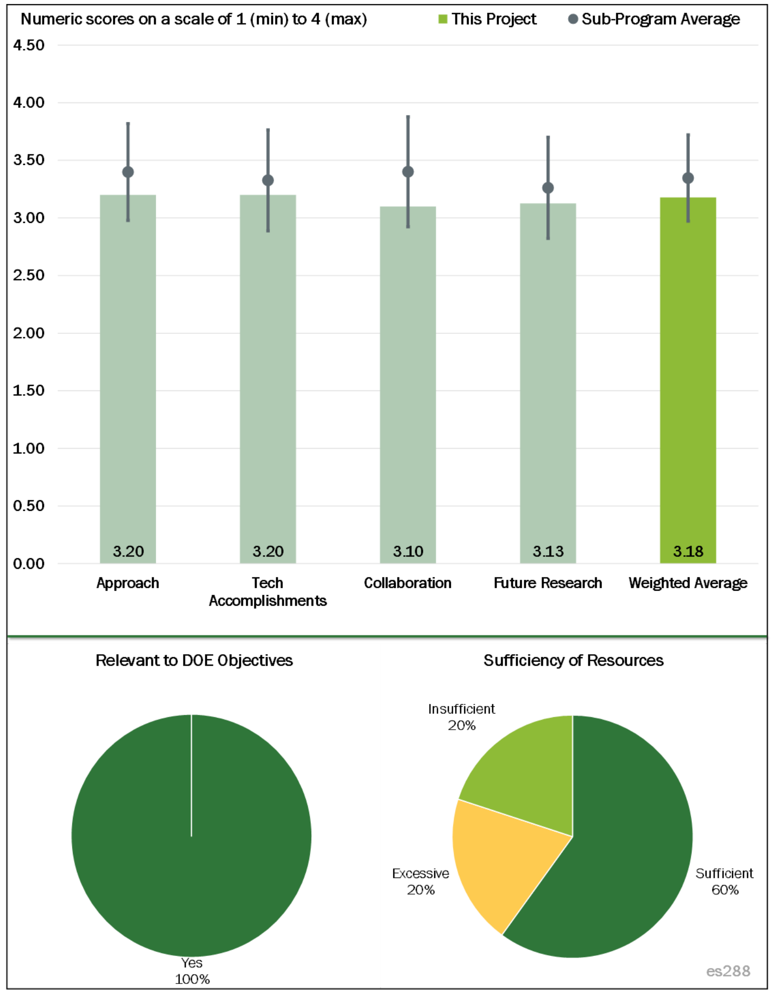

Figure 3-49 - Presentation Number: es288 Presentation Title: Construction of High-Energy Density Batteries Principal Investigator: Christopher Lang (Physical Sciences Inc.)

Presenter

Christopher Lang, Physical Sciences Inc.

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer remarked that to achieve the overall project objective of constructing a cell offering a 25% increase in cell energy density over the state-of-the-art, PSI followed a clear and well-designed path: construct cathode using their high active coating technique; increase charge voltage; increase active material loading in cathode; and fabricate lighter anode current collector. By following such a path, the energy density of the cell was gradually improved to meet the target value. The reviewer said that generally speaking, the approach to perform the work is effective and well-designed.

Reviewer 2:

The reviewer said that the scope seemed very broad and ambitious for SBIR. The reviewer said the project seemed to limit execution and follow through on the anode, which was the key contributor in the overall specific energy benefit. According to the reviewer, it would have been better to demonstrate that the cathode coating was robust to multiple suppliers, binders, and electrode loading.

Reviewer 3:

The reviewer said nice project concept on getting thicker electrodes to work, and need more effort in areas like this. The cycling results look promising. The reviewer said try to include more data using other protocols including high-temperature cycling, low-temperature power, and storage data. The reviewer would like to see more comparison on performance with state-of-the-art electrodes (lower loading), and/or standard current collectors.

Reviewer 4:
The reviewer said that results are very interesting, but there is no description of the coating material, coating process, etc., thus it is not possible to assess PSI’s technology, its manufacturability/scalability.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:
The reviewer remarked that the volumetric advantage of reducing the binder content looks to be significant but is not well promoted.

Reviewer 2:
The reviewer said the project should show exact calculations for energy density. However, if they are correct, this project appears to be hitting targets.

Reviewer 3:
The reviewer commented that so far, improvement of energy density could be clearly seen. By applying the high active (HA) coating technique and light composite anode current collector, the energy density could be improved. However, whether the energy density of the cell could reach the target still needs to be verified. Besides, some information needs to be further provided by PSI. The reviewer asked, first, how the cost of anode current collector compare with Cu current collector. Second, at high active material loading of over 35mg/cm^2, the reviewer asked how the performance of cathode prepared by the HA coating technique compares with the cathode prepared following traditional coating procedure. Third, as the cycling number of provided pouch cell data with high charge voltage is lower than 1,000 cycles, the feasibility of cycling the cell under high-voltage is still questionable.

The stability of the electrolyte should be responsible for this problem. The reviewer said that no data were shown for improving the stability of electrolyte, and it seems to be difficult to solve this problem in the remaining several months. In addition, it seems that the capacity of HA coated NCM-622 cathode tends to fade faster than baseline cell under either low charge voltage (4.2V) or higher charge voltage (4.3V). But, according to the reviewer, this fading rate is acceptable. In a word, whether the final output could meet the target still needs to be verified.

Reviewer 4:
The reviewer said that the cell data looks great, but insufficient information was provided to assess PSI's technology.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted excellent feedback from SKC.

Reviewer 2:
The reviewer said that PSI showed excellent collaboration and coordination with SKC Powertech. SKC PowerTech contributed a lot for punch cell fabrication process. However, according to the reviewer, based on the results so far, the contribution of ANL for characterization is rather too small.

Reviewer 3:
The reviewer commented that the project collaborations with a cell builder validate the approach. The reviewer asked where cost information comes from on the coating. It would be good to get a materials company involved.

Reviewer 4:

The reviewer noted that collaboration is not a SBIR requirement. PSI is working with ANL and SKC Powertech as a battery manufacturing partner, but the review is vague on what their levels of effort or contributions were.

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.

Reviewer 1:

The reviewer commented continue getting validation data in larger cell formats.

Reviewer 2:

The reviewer said that because the project is going to end, the future plan for demonstrating pouch cells with targeted energy density and cycle life is good. However, because no preliminary data were given for the adjustment of electrolyte to improve the stability of electrolyte at high-voltage and the cycle life of the cells cycling at high-voltage is insufficient, it is doubtable whether this work could be done in the last few months. The reviewer said that these issues should be figured out and worked on much earlier than this point.

Reviewer 3:

The reviewer noted that the project ends in six weeks from the AMR. The reviewer would like to see a finite element analysis (FEA) thermal analysis of the composite anode current collector cell design (less conductive than baseline) and the lower binder content cathode design (more conductive than baseline). Also, higher active loading slurry may enable faster throughput drying — economic benefit.

Reviewer 4:

The reviewer said that future work is only focused on a demonstrating aspect of the technology, no work proposed on improvement of the technology.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer said that battery energy density/specific energy gains through improved cell design should be strongly supported. The return on investment is higher and risk is lower than material or electrolyte discovery.

Reviewer 2:

The reviewer noted that projects that improve energy density of LIBs support DOE objectives.

Reviewer 3:

The reviewer commented that this project could help improve the energy density of LIBs and in return contribute to petroleum displacement.

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

Reviewer 1:

The reviewer commented that generally, the resources for this project have been sufficiently utilized and the stated milestones have been achieved on time.

Reviewer 2:

The reviewer said that the scope of the program was too broad.

Presentation Number: es289
Presentation Title: Advanced Polyolefin Separators for Lithium-Ion Batteries Used in Vehicle Applications
Principal Investigator: Weston Wood (Entek)

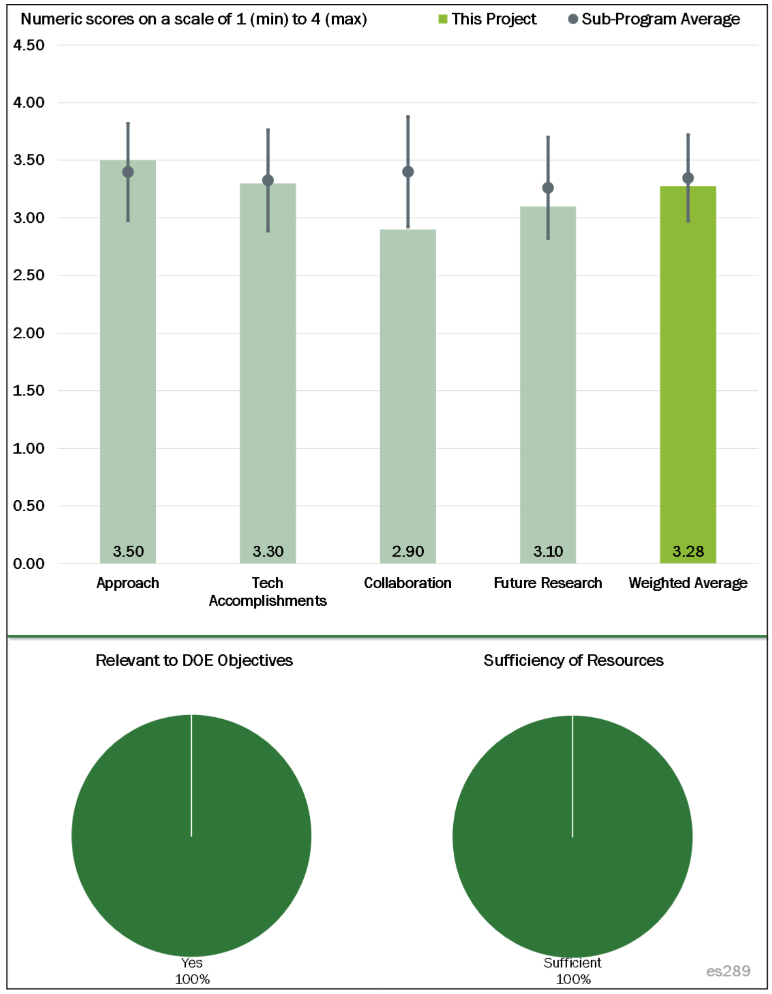

Figure 3-50 - Presentation Number: es289 Presentation Title: Advanced Polyolefin Separators for Lithium-Ion Batteries Used in Vehicle Applications Principal Investigator: Weston Wood (Entek)

Presenter

Weston Wood, Entek

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer noted a well outlined experimental plan to address barriers and meet the objectives.

Reviewer 2:

The reviewer said it was great to see work on separators included in the DOE portfolio. The reviewer expressed concern on moisture sensitivity in a typical manufacturing environment. The reviewer said that there is not enough information about cost in the presentation.

Reviewer 3:

The reviewer commented that this work was performed well and the key points, including the wettability and safety, were investigated in a well-organized way. One concern is that the resistance/ ion mobility of the entire cell with the coated separator has not been touched, which would be an important factor for this work.

Reviewer 4:

The reviewer remarked that it appears dendrite penetration was added to scope. The reviewer was unclear if the process can be applied only to an Entek/PE separator, but Entek is not really motivated to establish this.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance

Reviewer 1:

The reviewer observed good test data for separator — penetration, etc. The reviewer said that more electrochemical testing is needed, but what the project team has looks good. The reviewer was unclear how the project will meet the electrolyte goal for 5.0V cells in the time remaining.

Reviewer 2:

The reviewer said that it is good to see the improvements on safety, Li penetration suppression, wettability, and NCM cell performance. One suggestion is to conduct the ionic conductivity and resistance test as soon as possible, which may affect the entire performance of this technique.

Reviewer 3:

The reviewer said that initial films were prepared using dip coating. The reviewer was not clear what the scalable process/integration with baseline separator production is, but Entek is well qualified to understand scalability. The reviewer would like to see large-format cell abuse testing. The reviewer remarked need more clarity on Entek benefits compared to other commercially available alumina coated separators.

Reviewer 4:

The reviewer was not clear if the data/results shown are versus a commercial separator, and if so, what are the guarantees that Entek's scale-up process produces same consistent material.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer observed appropriate collaborators for cell build and testing.

Reviewer 2:

The reviewer said that Farasis seemed not enrolled too much about the high-voltage cell developments at the moment.

Reviewer 3:

The reviewer pointed out that collaboration and coordination is not a requirement of the SBIR program and this may be outside what a private company is willing to share.

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.

Reviewer 1:

The reviewer remarked that a great enhancement of the separator performance has been achieved. Some key factors, including ionic conductivity, moisture removal, and high-voltage resistance, have been put forward for future study. One concern is that some of these issues are lack of investigation based on the data provided. The reviewer pointed out that it is challenging to solve them in the last phase of this project.

Reviewer 2:

The reviewer did not see a specific path to 5V shown. This is a hard problem. The reviewer also said that the moisture problem is not addressed enough.

Reviewer 3:

The reviewer would prefer to see future work address the moisture risk and in-line coating. High voltage is a complex problem to test effectively and not an immediate market. For example, electrolyte work is outside the scope of the program. In this reviewer's opinion, building a 25 Ah 5.0V cell would be premature.

Reviewer 4:

The reviewer asked what scale is planned to be used for the demonstration of the coating methods.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer commented that this project shows good enhancements of the separator safety and possible cost reduction of separator coating. So this technology will be beneficial to the practical battery application.

Reviewer 2:

The reviewer noted that abuse-tolerant separators are in the market. Entek seems to have demonstrated that this approach has advantages over coated separators if moisture issues can be managed.

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 main stated milestones have been achieved timely. One thing that can be improved is progress of the high-voltage resistance and ionic conductivity tests, which can be conducted based on the achieved results.

Presentation Number: es290
Presentation Title: Hybrid Electrolytes for PHEV Applications
Principal Investigator: Surya Moganty (NOHMs Technologies)

Presenter

Surya Moganty, NOHMs Technologies

Reviewer Sample Size

A total of four reviewers evaluated this project.

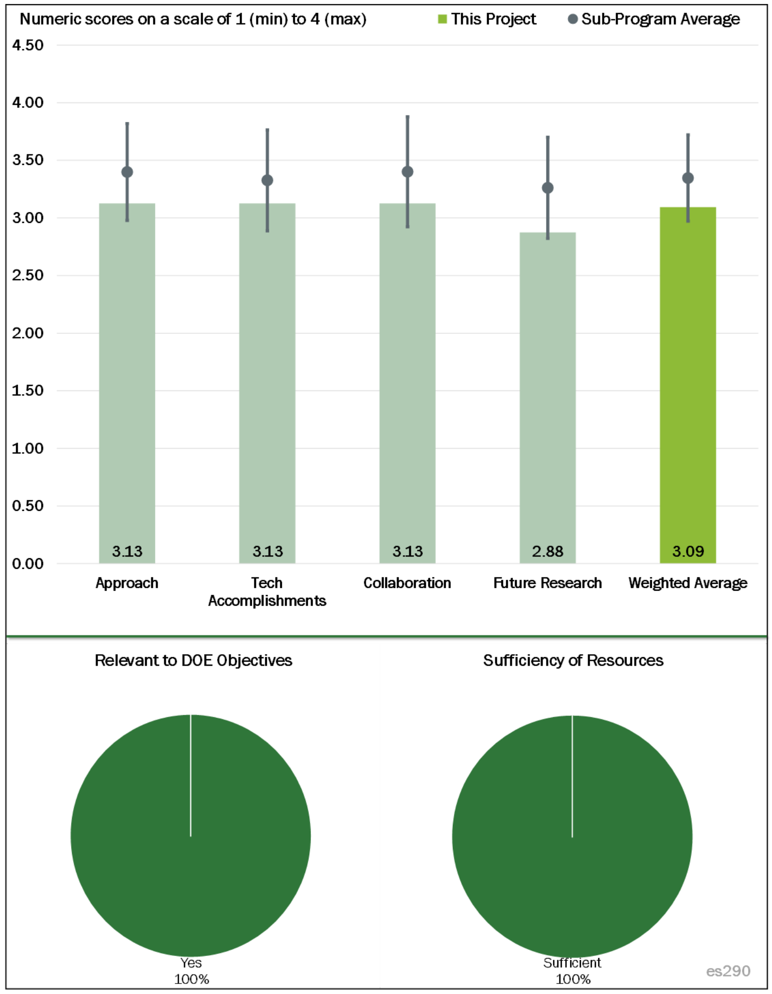

Figure 3-51 - Presentation Number: es290 Presentation Title: Hybrid Electrolytes for PHEV Applications Principal Investigator: Surya Moganty (NOHMs Technologies)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer stated that the objective here is to develop safe high-voltage electrolytes based on functionalized ionic liquid (IL)-based electrolytes that exhibit high conductivity, excellent electrode stability, and a wide operational temperature range for high-voltage (4.5 to 5V) L)-ion batteries. The reviewer explained that state-of-the-art organic electrolytes have inadequate oxidative stability at high-voltages (greater than 4.5V) and have inherently poor abuse tolerance. IL electrolytes, on the other hand, have adequate safety and high-voltage stability, but the stability at anode potentials, low-temperature performance, and cost are still issues. The reviewer elaborated that the specific objectives here are to develop the functionalized IL electrolytes, demonstrate their performance in 2 Ah pouch cells with Ni Mn oxide (NMO) and Ni Mn Co oxide (NMC) 532 cathodes, perform a design and cost study of electrolyte production, and finally, deliver 10 Ah pouch cells to DOE for further validation. The reviewer added that the approach is to design functionalized ILs based on literature data and in-house proprietary knowledge, synthesize and characterize them for transport and electrochemical properties, evaluate them in coin and in single-layer pouch cells, and later scale up to 2-10 Ah cells with the NMO and NMC high-voltage cathodes. As mentioned above, ILs have shown promise based on their oxidative stability and safety, but their stability at the anode potentials, performance at low temperature, and cost have been the issues in their implementation. The reviewer concluded that overall the approach is useful in addressing two main technical barriers of the organic electrolytes in Li-ion cells, and the project is well designed and integrated with other efforts.

Reviewer 2:

The reviewer stated that NOHMs Technologies develops IL-based electrolytes with high-voltage limits (4.5 to 5V) and better temperature stability for Li-ion, adding that this is a unique project concentrated in electrolytes for a high-voltage (greater than a 4.5V) battery.

Reviewer 3:

This reviewer understands from the discussion that the ILs component is essentially another additive to the electrolyte but added that the exact role in the overall stability is not really addressed. This reviewer thought that the effort to examine cost will be particularly useful.

Reviewer 4:

The reviewer replied that the project team is developing new molecules to add to standard electrolytes that are safe and that do not make any properties worse.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer affirmed that excellent progress has been made in designing and demonstrating new IL-based electrolytes compatible with high-voltage cathodes, elaborating that the functionalized ILs have ionic conductivities comparable to the conventional organic electrolytes but have improved stability towards high-voltage cathodes, evident from the X-ray powder diffraction (XRD) studies of the cathodes in contact with these electrolytes, even at warm temperatures. Good cyclic stability has been demonstrated in pouch cells of 2 Ah - 10 Ah at room temperature and elevated temperature (45^{o}C). The reviewer explained this is partly made possible with the electrolyte additives (some proprietary) which show similar improvement in these ILs as in organic electrolytes. Several cells of 2 Ah-10 Ah have been delivered to the USABC for its assessment, which met the USABC performance targets, including low-temperature cracking and good cyclic stability at moderately high discharge rates of C/2 at warm temperatures.

The reviewer stated, however, that it should be realized that the cathode loading is rather low (15 mg/cm^2), which may result in low specific energy and energy densities for these cells. (The reviewer suggested including those values for the large pouch cells.) The reviewer elaborated that thicker electrodes will increase the current densities, which may adversely affect the rate capability. The reviewer also observed that in some of the abuse tests performed at SNL, the cells exhibited thermal runaway, which is a bit puzzling with these IL electrolytes. The reviewer remarked that the cost analysis here shows that it would be possible to meet the DOE cost targets with the electrolytes. The reviewer concluded that overall the results are quite encouraging for the use of ILs in lieu of organic electrolytes and that the technical accomplishments are notable and the progress is good and consistent with DOE goals.

Reviewer 2:

The reviewer indicated that there seems to be good progress in the program with a fairly wide range of tests being conducted, mostly around standard cell testing.

Reviewer 3:

The reviewer explained that NOHMs Technologies has developed IL electrolytes with higher decomposition temperature (greater than 300^{0}C) and better cycle life (350 cycles with 80 retention), adding that higher loading cells (10 Ah NMC) are under evaluation. The reviewer also noted that the XRD analysis does not say much about the advantages of NOHMs Technologies' electrolytes over others in terms of maintaining of the structural stability of cathode.

Reviewer 4:

Although NOHMs Technologies' electrolytes perform better than simple electrolytes with no additives, this reviewer stated that the recipient has no evidence that its electrolytes perform any better than state-of-the-art electrolytes that have already been reported, or even commercially available (4.35V) electrolytes. Without such comparisons, this reviewer cannot evaluate whether the recipient is making any real progress.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that there are ongoing collaborations with A123 Systems for the fabrication of cathodes and small format cells construction (NMC and NMO) and small format cells for proof of concept and fabrication of 2 to 10 Ah prismatic pouch cells with NOHMs Technologies electrolyte. There was collaboration with Xerox on the cost analysis of high-volume electrolyte production and with the DOE laboratories in the performance and safety testing of cells.

Reviewer 2:
NOHMs Technologies is working with A123 Systems (electrode and pouch cell construction) and XEROX (high-volume electrolyte production). It also collaborated with SNL in battery abusing test.

Reviewer 3:
The PI has extensive collaborations with a couple of companies.

Reviewer 4:
The reviewer replied okay.

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.

Reviewer 1:
The reviewer explained that the proposed future studies are to: Complete the accumulation and analysis of USABC 2 Ah NMO test results; downselect formulation for 10 Ah NMO build; complete cost model for final electrolytes; and fabricate and deliver 30 NMO 10 Ah pouch cells with NOHMs Technologies electrolyte. The reviewer suggested it would be helpful if specific energy and energy densities realized in these cells and also get some handle on the abuse tolerance and strategize on how further improvements can be made here. The reviewer concluded that these studies are consistent with both project and DOE goals.

Reviewer 2:
The reviewer replied that NOHMs Technologies listed detailed steps for future works including delivery of 10 Ah NMO 10 pouch cells and cost modeling to complete the project.

Reviewer 3:
The reviewer noted that the project is ending in 2017 and the PI is working on the final deliverables.

Reviewer 4:
This reviewer does not see a clear path forward beyond trying a large number of molecules

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer offered that performance and safety of electrolyte at high-voltage range is critical for increasing the capacity of LIBs to be used in electric vehicles.

Reviewer 2:
The reviewer affirmed this project is highly relevant for high-energy density cells.

Reviewer 3:

The reviewer remarked that low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles, elaborating that conventional cathode materials have low specific energy and energy density. In addition, the reviewer said, the use of emerging high-voltage/capacity cathodes is precluded by the organic electrolytes, which also pose safety issues. Explaining that alternate stable and safe electrolyte are needed to improve the specific energy and energy density and safety of LIBs, the reviewer concluded that these issues are being addressed by the project.

Reviewer 4:

The reviewer responded 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:

Based upon the demonstrated works and the wide collaboration, the reviewer believes that the NOHMs Technologies system has sufficient resources to achieve the stated milestones in time.

Reviewer 2:

The reviewer agreed that the resources are adequate for the scope of this work.

Reviewer 3:

The reviewer stated the resources are sufficient.

Reviewer 4:

The reviewer responded okay.

Presentation Number: es291
Presentation Title: SAFT-USABC 12V Start-Stop Phase II
Principal Investigator: Alla Ohliger (Saft)

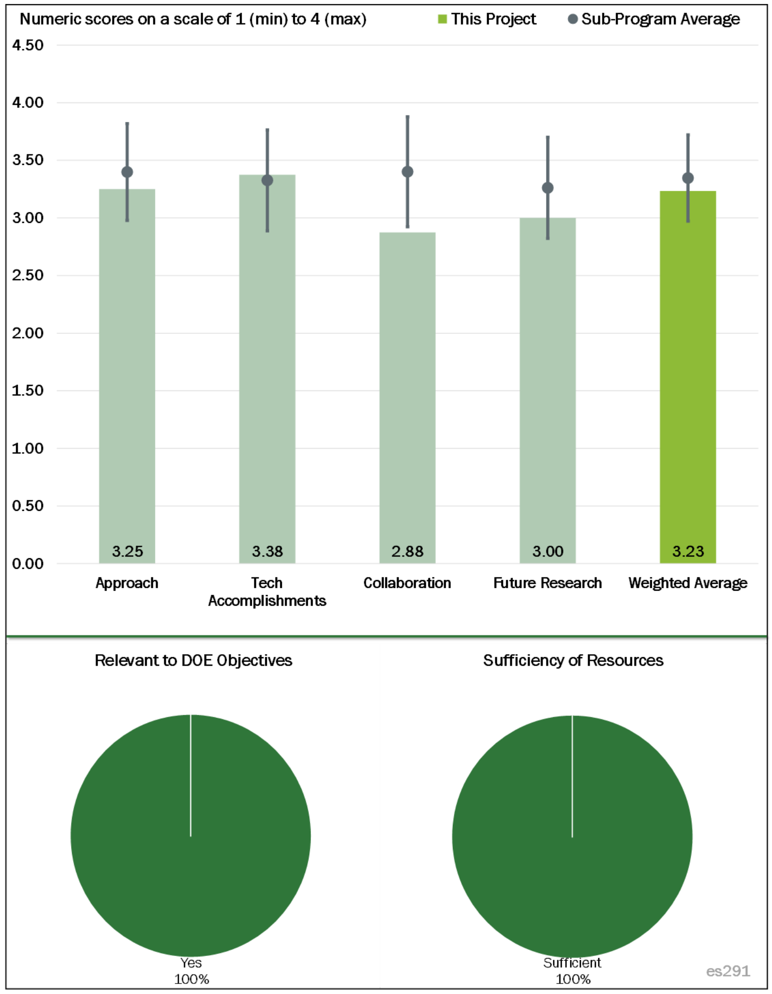

Figure 3-52 - Presentation Number: es291 Presentation Title: SAFT-USABC 12V Start-Stop Phase II Principal Investigator: Alla Ohliger (Saft)

Presenter

Joong Sun Park, Saft

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer observed that the objective here is to develop an advanced, high-performance battery module for 12V start-stop vehicle (12VSS) applications, in compliance with the USABC performance requirements, based on SAFT's proprietary lithium titanium oxide (LTO) anode-based (with Al current collector) LIB technology. The reviewer explained that the goal is to deliver to USABC 12VSS module assemblies with pouch cells in thermoplastic module along with battery management electronics, adding that the project cost of cell module is under $220. The reviewer elaborated that the approach involves the use of an LTO anode, which has the advantages of high-power capability, long life, and being free of Li plating, and an LMO cathode. Different electrolyte blends (binary and ternary) are being examined for improved low-temperature conductivity, improved low-temperature cranking, and high-temperature stability (gassing). In parallel, the reviewer continued, a simple battery pack design is being developed with supporting thermal modeling. The reviewer concluded that the approach addresses the technical barriers, and the project is well-designed, feasible, and integrated with other vehicle technologies projects.

Reviewer 2:

The reviewer explained that the project led by Saft Jacksonville is concentrated on temperature stability and gassing control based on the team's proprietary LTO LIB technology. The objectives are delivering high-performance 46 Ah cells and modules, and identifying a path to full commercialization. The reviewer concluded that the technical barriers are well addressed.

Reviewer 3:

The reviewer replied that while this is a valuable project, it is unclear how the team plans to address temperature and gassing problems. The reviewer, added, though, that some progress has been made.

Reviewer 4:

The reviewer commented that the PIs seem to understand the problems and have a good plan to attack the issues but that it is more than a bit disappointing that the PIs went away from the polymer monoblock case. Also, the reviewer said, their choice of going to LMO presents a lot of challenges for long life. This reviewer would have used NMC and maybe tried to work in an extra cell to attack the cold-cranking issue, but that certainly would have impacted the cost.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer observed that because the key requirement for the USABC program is the cold cranking, much of the recent effort was focused on identifying electrolytes with good low-temperature conductivity and also high-temperature stability. The reviewer recounted that the first deliverable cells delivered to USABC for cold crank and life testing have met the energy/power requirement at RPT6 at 45ºC and the second deliverable cells Li ion Mn oxide (LMO)/LTO cells with optimized LTO anode and electrolyte formulations have passed cold crank at -30ºC after removing 360-Watt-hour (Wh) scaled energy. The reviewer continued that the modified electrolytes (maybe with a combination of ester blends and LiFSI salt and additives based on the data shown here) have provided improved low-temperature cranking, as well as reduced gassing and impedance growth during storage (at warm temperatures) and cycling.

In addition, the reviewer said, the design for the 46 Ah pouch cell has been completed and the tooling required to manufacture these cells has been identified. Thermal analysis of this module suggests survivability after exposure to at 105ºC for 15 minutes, the reviewer observed, and cost analysis indicates that the projected cost of the pouch cell module is approximately $160. Finally, the reviewer, explained, the supplier for low-cost battery management electronics were screened and downselected. The reviewer found that these accomplishments are encouraging and the progress is quite consistent with the project objectives and DOE goals.

Reviewer 2:

The reviewer remarked that while the technology needs further development, the project has clearly shown progress in a number of areas.

Reviewer 3:

The reviewer stated that the two cells delivered so far passed the energy/power requirement at RPT6 at 45^{0}C (first cell) and cold crank at -30^{0}C (second cell). The reviewer added that it is expected that the team will deliver the 12VSS prototype at the end of the project.

Reviewer 4:

The reviewer concluded that it is too early to say if the team's approach has a good chance for success. Noting that the team is trying novel electrolytes (esters) to overcome the low-temperature problems, the reviewer explained that it is unclear how it will address the high temperatures that are under the hood at reasonable cost, pointing out that the team trying to modify the LTO for better cold crank.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer said that there is collaboration within Saft and a few external partners and with the DOE national laboratories for the assessment of the delivered cells and modules.

Reviewer 2:

The reviewer stated that Saft tested cold crank and life performance for under the hood conditions at INL.

Reviewer 3:
The reviewer replied okay.

Reviewer 4:
The reviewer replied that collaborations are rather limited.

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.

Reviewer 1:
Noting that the project is coming to an end this year, the reviewer observed that the planned studies in the remaining few months will focus on decreasing gassing while maintaining superior cold crank performance, life, and reduced gassing. These will also include improvements in electrode formulation (e.g., porosity, binder, and carbon percolation network), surface coatings by ALD or dry-coatings, and electrolyte optimization, i.e., solvent and salt additives. In parallel, the reviewer explained, other efforts will address the module and system development to build prototype 12VSS modules. The eventual goal is to develop and manufacture over 20 fully operational batteries with an integrated electronic system. The reviewer stated that these studies are well planned and in tune with the goals of the project and needs of 12VSS LIBs.

Reviewer 2:
The reviewer remarked that sassing seems to continue to be an issue and suggested that the PIs may want to consider alternative sources of LTO from companies that "claim" to have solved the problem.

Reviewer 3:
The reviewer noted that Saft listed steps in further improving the electrode formulation to decrease gassing and improve the life of LTO at high temperatures.

Reviewer 4:
The reviewer replied that it is unclear how the project team will solve their problems

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer observed that replacing the conventional 12V lead-acid batteries with LIBs for start-up applications will reduce battery mass and volume (by 60%), improve the service life, and reduce maintenance. The reviewer also noted that their rapid recharge reduces the load on the alternator as they retain more power and are able to handle the charge faster than lead-acid batteries. All these characteristics will result in reduced fuel consumption and thus reduced CO_2 emissions. Noting that current active materials have low specific power to support cranking, especially at low temperatures, the reviewer stated that new active materials in conjunction with advanced electrolytes are needed to provide low-temperature cranking and high-temperature resilience. Also, the reviewer said, simpler pack designs and battery management systems are essential to make the LIBs a viable replacement. The reviewer judged that this project is aimed at addressing these challenges.

Reviewer 2:
The reviewer said this is highly important for the auto industry.

Reviewer 3:
The reviewer stated that temperature stability is critical for battery safety and must be well controlled in electric vehicles.

Reviewer 4:
The reviewer answered that the work 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 reviewer found that the resources are adequate for the scope of the project to meet the stated milestones in the scheduled time.

Reviewer 2:
The reviewer stated that the resources are sufficient.

Reviewer 3:
The reviewer said that Saft demonstrated that it can conduct the project with its own technologies and in collaboration with INL for some testing work.

Reviewer 4:
The reviewer replied okay.

Presentation Number: es293
Presentation Title: A Closed Loop Process for the End-of-Life Electric Vehicle Lithium-Ion Batteries
Principal Investigator: Yan Wang (WPI)

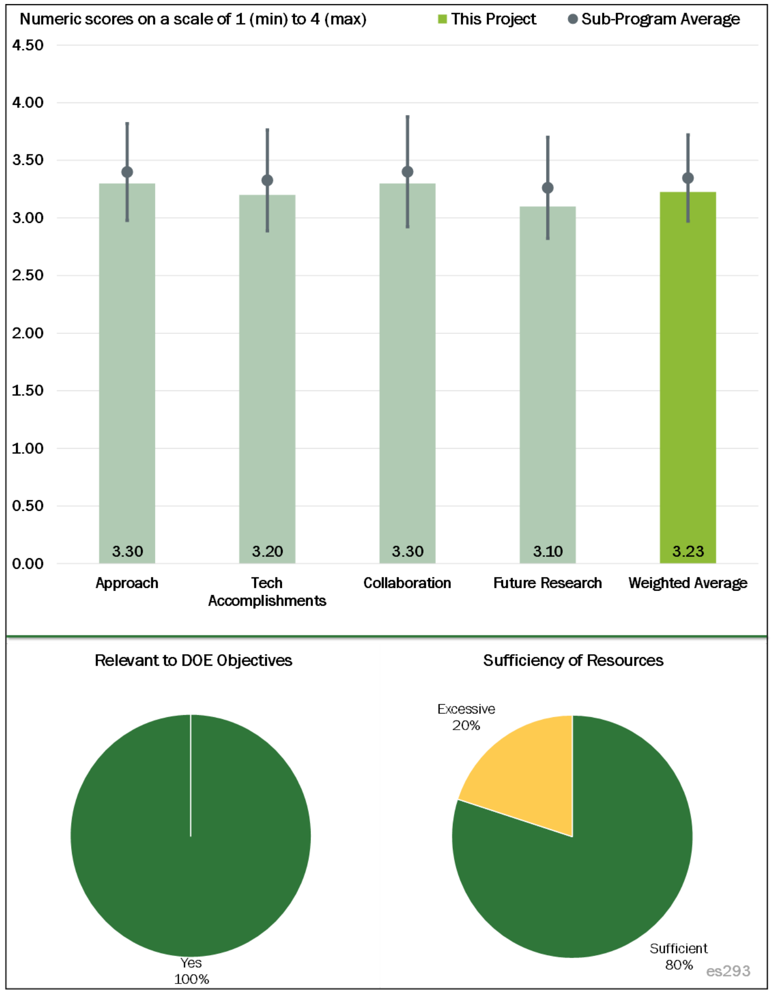

Figure 3-53 - Presentation Number: es293 Presentation Title: A Closed Loop Process for the End-of-Life Electric Vehicle Lithium-Ion Batteries Principal Investigator: Yan Wang (WPI)

Presenter
Yan Wang, WPI

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer affirmed that this is the project that addresses a very critical issue of battery application, specifically, recycling. The reviewer praised the PI has having demonstrated an industrially viable process to recycle the battery and recover the most valuable elements, Ni and Co, and reuse them to make new cathode powders.

Reviewer 2:
The reviewer observed that the large amount of end-of-life battery waste causes serious environmental issues and stated that this project shows an effective and outstanding method of dealing with battery waste and recycling the metals Ni, Co, Mn, iron, and Cu via dissolving cathode material in strong acid and precipitating new cathode material. The reviewer cautioned, though, that one concern of this strategy is the cost of this approach compared with that of industry large-scale production. The reviewer recommended evaluating the cost of each approach of producing cathode material.

Reviewer 3:
The reviewer replied that this is a very practical project and approach to recycling but asked how is this recycling process different/novel/more cost-effective than Umicore's approach. The reviewer also stated that much more electrochemical testing is required to conclude that the recycled materials are of adequate quality.

Reviewer 4:
The reviewer responded that feasibility is done at meaningful 20 to 30-kilogram (kg) scale, remarking that this is an accomplishment for an academic-led program. The reviewer noted that a 0.5-ton pilot plant is planned, although it was unclear what relationship that is to the present program. The reviewer concluded there needs to be validation that large-scale shredding operations can be performed safely.

Reviewer 5:

The reviewer stated that work done on developing NMC material from the recycling stream, which is comparable to product on the market, is valid as an academic effort, but this was the main focus of the investigation. The reviewer commented that there is nothing novel in the recycling approach, elaborating that the team should have a clear path forward to demonstrate feasibility on the industrial scale and be prepared to answer questions on cost, waste disposal of contaminated liquid streams, general water usage, plant footprint sized to be profitable, etc.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer remarked that by recycling the battery waste, this project can make large batch of new cathode material at kg scale with novel electrochemical performance.

Reviewer 2:

The reviewer stated that there is good analytical comparison, but a lack of electrochemical evaluation and asked if the team has done a cost assessment.

Reviewer 3:

This reviewer would like to see two improvements: First, inclusion of touch time/labor cost for discharging and isolating cells. The reviewer pointed out that an issue is can commingled cell chemistries or cell OEMs be accommodated or will there need to be a sorting operation. Second, accounting for the waste stream costs and management, neither of which were. With the claimed 80% yield, the reviewer observed, there is a lot of Cu and Ni unaccounted for and potentially dispersed in the operation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer affirmed that this project shows not only the recycling of battery waste to make new cathode material, but also collaborating with A123 Systems to test its battery performance to further prove the effectiveness of the proposed approach.

Reviewer 2:

The reviewer replied that A123 Systems is a good cell partner, but the project also needs a materials company involved here.

Reviewer 3:

The reviewer stated that the project would benefit from NMC material supplier such as BASF, Umicore, etc., adding that the roles of many partners was not clear.

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

Reviewer 1:

The reviewer stated that large-scale recycling of batteries may encounter some new problems and that it can further tell the effectiveness of this method of recycling battery waste. The reviewer noted that the approach mentioned the need for recovery of Ni, Co, and Mn in this research. One more thing the reviewer added about waste LIB is the recovery of Li existing in the cathode and electrolyte. Pointing out that the price of Li salts goes up quickly with increasing demand of LIB, the reviewer recommended looking for an effective strategy of recycling of Li in waste LIB.

Reviewer 2:

The reviewer replied that detailed analytical studies on the cathode materials should be helpful. For example, the reviewer noted, there is no indication that the mixed metal hydroxide precursor is being washed after co-precipitation with sodium hydroxide and asked if, in general, there is an in-process quality control to ensure chemical purity.

Reviewer 3:

The reviewer had two comments: First, the activities listed as remaining challenges are too sparse, elaborating that here is not enough electrochemistry data to jump to 2 Ah cells. The reviewer said that much more testing will be needed and that this should be done before scaling up the process. Second, a full economic model should be included to answer questions such as what do the waste streams look like now and is the cost of managing those included here.

Reviewer 4:

The reviewer found that the economic model is not convincing yet, noting that a process with 80% yield is not closed loop. The reviewer added that the model must also account for diversity in pack design, cell design, cell chemistry, state of health, etc., and must be correct on the battery pack Cu recovery, which is likely the high-value component of the pack. The reviewer pointed out that this is also an opportunity to identify design rules and best practices to enable standardized mechanical disassembly as well as recovery and chemical isolation of materials.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer stated that the LIB plays an important role in energy storage for the renewable energy and that the project demonstrates an effective method of recycling battery waste, which may further reduce battery cost and improve the utilization of renewable energy.

Reviewer 2:

The reviewer answered that Cu, Ni, and Co recovery can improve the economics of large-scale energy storage.

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

Reviewer 1:

The reviewer responded that the project demonstrates sufficient resources of battery waste treatment, the recycled new cathode material preparation and testing.

Presentation Number: es296
Presentation Title: Development and Validation of a Simulation Tool to Predict the Combined Structural, Electrical, Electrochemical, and Thermal Responses of Automotive Batteries
Principal Investigator: Chulheung Bae (Ford Motor Co.)

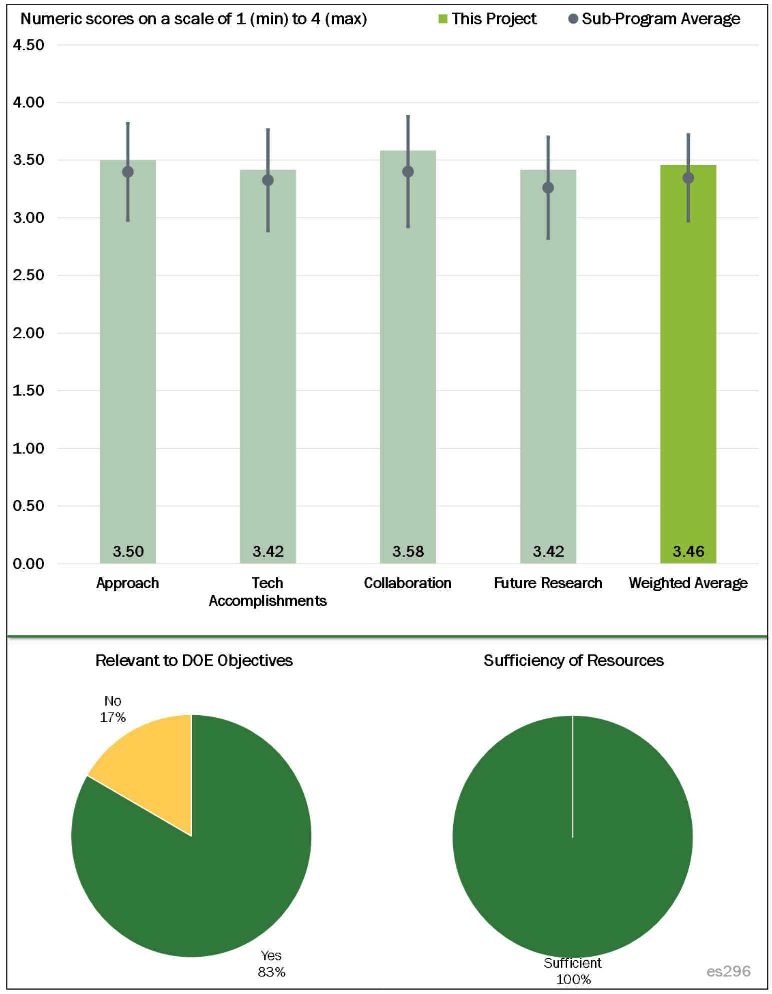

Figure 3-54 - Presentation Number: es296 Presentation Title: Development and Validation of a Simulation Tool to Predict the Combined Structural, Electrical, Electrochemical, and Thermal Responses of Automotive Batteries Principal Investigator: Chulheung Bae (Ford)

Presenter
Chulheung Bae, Ford Motor Co.

Reviewer Sample Size
A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer praised the approach as appearing to be well conceived, logical, and suitable for the associated objectives.

Reviewer 2:
The reviewer affirmed that the project is well designed and appears to leverage experiments and developments in other DOE and National Highway Traffic Safety Administration (NHTSA) projects, as well as internal resources at Ford.

Reviewer 3:
The reviewer agreed that the approach clearly identifies the gap in existing simulation capabilities and that a path to address the gap is identified and concurred that progress is made with the support of software developer.

Reviewer 4:
The reviewer stated that the vehicle and battery crush worthiness is very well defined.

Reviewer 5:
The reviewer responded that the approach seems good, but observed that when using solid elements, there needs to be at least three elements through thickness and suggested that maybe a mesh-independent study should be conducted. The reviewer would also like to see more information on heat transfer, and asked the project team how it considers advection or is it all conduction and asked the team to provide details on heat generation. This reviewer assumes the team is calculating heat release based on the Gibbs energy of reactions at electrodes.

Reviewer 6:
The reviewer stated that while the models with data comparison are always good, it is unclear that the many ways a cell can or cannot fail are well comprehended in a single fault failure model. For example, the reviewer offered, the separator could tear or just stretch or it could stretch and then tear. The reviewer said that this does not seem to be covered inherently, or it could be but only by manual intervention.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer affirmed that noticeable progress has been made with technical accomplishments with the layered solid element approach, adding that the initial accomplishments and comparative analysis to the test show promising results. The reviewer concluded overall, nicely done.

Reviewer 2:
The reviewer agreed that accomplishments seem good. Remarking that this is a necessary model to connect all aspects, the reviewer said it is good to see some code development.

Reviewer 3:
The reviewer stated that the project developed model and reduced computation time and that there is reasonable correlation of data. The reviewer further stated set up external short and module simulations.

Reviewer 4:
The reviewer replied that model development is complete.

Reviewer 5:
The reviewer responded that the work for the alpha version multi-physics solvers and material models appears to be delayed, and that the technical progress appears to be reasonable considering that the PI for this project has been changed two times recently.

Reviewer 6:
The reviewer commented that the layered solid method's performance with respect to bending moment should be evaluated.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer praised the work as very well coordinated and collaborated with software developer and other research establishments to address the critical mission needs both from material characterization and simulation capabilities points of view.

Reviewer 2:
The reviewer agreed that the project members appear to have good collaboration among each other and the project has leveraged experiments and developments in other DOE and NHTSA projects, as well as internal resources at Ford.

Reviewer 3:
The reviewer stated there is good collaboration with LS-DYNA team and added that this is a good use of LS-DYNA if one is getting assistance with code development.

Reviewer 4:
The reviewer replied that collaboration with ORNL, (LBNL, and SNL is sufficient for the development.

Reviewer 5:
The reviewer commented that really only internal collaboration between main partners was made clear.

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

Reviewer 1:
The reviewer affirmed that the proposed future research is well thought out and captures the critical needs.

Reviewer 2:
The reviewer agreed that the future research seems good but suggested focus on validation. The reviewer would also like to see a mesh study.

Reviewer 3:
The reviewer stated that the revision and fine tuning of the model will result in a better model.

Reviewer 4:
While agreeing that the proposed future research is reasonable, this reviewer expressed concern about whether this project can be kept moving slowly with PIs not replaced so often.

Reviewer 5:
While concurring that the proposed work is good, the reviewer said there is no obvious effort to look at the range of crush results that occur in duplicates of the same field tests or how to capture that with the model.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer agreed there is excellent relevance.

Reviewer 2:
The reviewer affirmed that this project supports overall DOE objectives of petroleum displacement because it facilitates the usage of LIB systems (and thus decreasing the size of any required petroleum-fueled power source) by further developing LIB modeling and simulation capability for design and analysis purposes.

Reviewer 3:
The reviewer said this project addresses DOE objectives of promoting vehicle electrification by developing models and validation on automotive batteries' response to crash-induced crush and short circuit, overcharge, and thermal ramp.

Reviewer 4:
The reviewer responded that the model will accelerate battery development and system integration.

Reviewer 5:
The reviewer observed that reduction in cost and improved abuse tolerance are both needed work and goals of this project, adding that if this is achieved, batteries will be more reliable and less expensive, and this, in turn, will drive reductions in gas use by increasing electric miles driven.

Reviewer 6:
The reviewer disagreed, remarking that the project is characterizing batteries from mechanical, thermal, and electrical points of view and is therefore not relevant to petroleum displacement.

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

Reviewer 1:
This reviewer stated that this project is a collaboration between software developer and material characterization and that all the milestones are being addressed in a timely fashion.

Reviewer 2:
The reviewer agreed that funding and resources are sufficient.

Reviewer 3:
The reviewer replied it seems fine.

Reviewer 4:
This reviewer was concerned whether the contractor can keep the PIs stable in conducting the proposed research work.

Reviewer 5:
The reviewer said that resources are on the edge. The reviewer remarked that the roughly $1.2 million is somewhat high for the work generated. While not badly overfunded, the reviewer stated that this is not as efficient as many of the other projects in the portfolio.

Presentation Number: es298
Presentation Title: Efficient Simulation and Abuse Modeling of Mechanical-Electrochemical-Thermal Phenomena in Lithium-Ion Batteries
Principal Investigator: Kandler Smith (National Renewable Energy Laboratory)

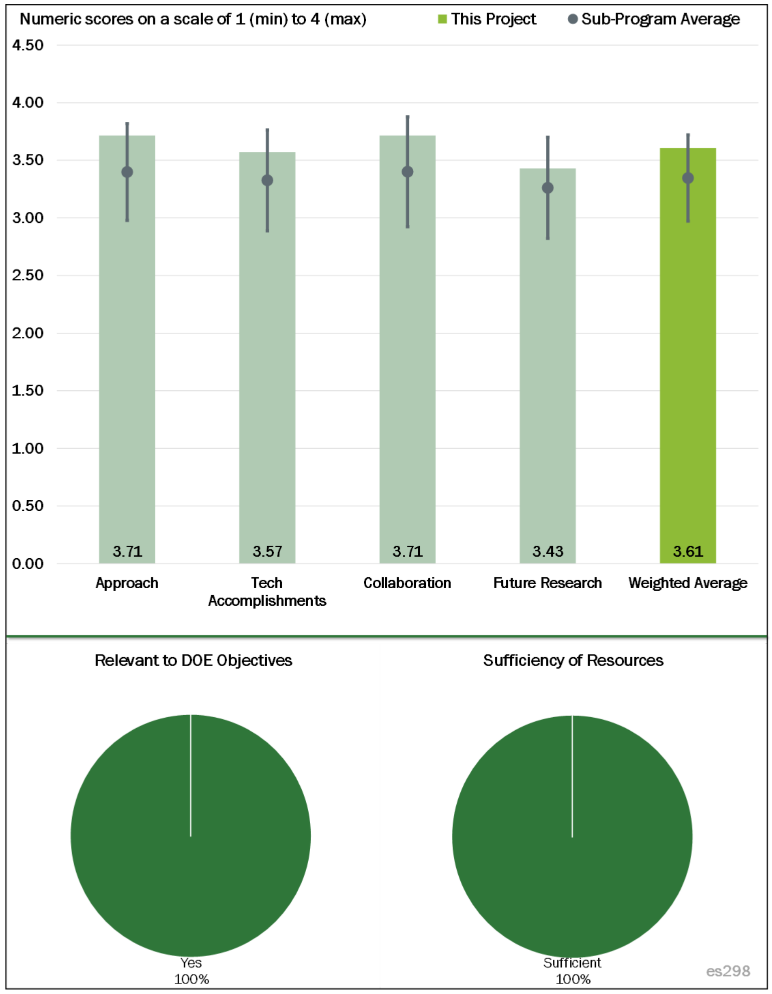

Figure 3-55 - Presentation Number: es298 Presentation Title: Efficient Simulation and Abuse Modeling of Mechanical-Electrochemical-Thermal Phenomena in Lithium-Ion Batteries Principal Investigator: Kandler Smith (National Renewable Energy Laboratory)

Presenter

Shriram Santhanagopalan, National Renewable Energy Laboratory

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that the gap between material R&D and computer-aided engineering (CAE) modelling tools addressed substantially to reduce the computational burden. The reviewer said that one of the big questions is how much of the material R&D data can be transferred to the computer-aided engineering of batteries (CAEBAT) tools, and asked if it is necessary to develop a user material model to capture the material behavior effectively.

Reviewer 2:

The reviewer said that a high-fidelity model of all aspects of a battery that works rapidly would be very helpful in design and especially safety testing of cells and that this project is well arranged to do this with a group to drive the simulations faster and two groups to increase model quality. The reviewer said that a key is validating against real data and that this is also part of the plan. The reviewer believed there is enough planned to provide high confidence and that predictions rather than posttest simulations clearly carry more gravitas. The reviewer said that the cell response is quite variable especially in abuse and so significant testing is needed to generate the scope of responses.

Reviewer 3:

The reviewer said that the time-scale separation method used as part of the reduced order modeling (and documented in the paper "Efficient and Extensible Quasi-Explicit Modular Nonlinear Multiscale Battery Model: GH-MSMD") is an excellent approach.

Reviewer 4:

The reviewer said the project is an excellent collaboration between national laboratories, DOE, and universities.

The reviewer would prefer to on Slide 16 see a design of experiments (DOE) fractional or full factorial study with reduced set of experiments considering sample input and output. In reference to Slide 11, the reviewer hoped instability of electrolyte has been considered. In reference to Slide 20, the reviewer hoped safety by lightweighting/right-sizing is addressed, and in reference to Slide 24 the reviewer asked if that will be adequate to prevent thermal runways and capacity loss.

Reviewer 5:

The reviewer said that the approach for Task 1 seems like a good approach and that there needs to be more done to propagate uncertainty through model. The reviewer noticed error bars are on order of diffusion coefficient.

The reviewer said that the approach for Task 2 seems okay. The reviewer said that the project is using an explicit FEA model (LS-Dyna) but the strain rates that the project are experimentally testing at are static. The reviewer recommended quickly moving on to higher strain rates, this is what LS-Dyna was made to look at.

The reviewer said that it might be help to define “Abuse” as this is not a well-defined term in the materials community. The reviewer would like to know does it mean fatigue, does it mean dynamic loading, or does it mean friction.

Reviewer 6:

The reviewer said that the project appears to have addressed technical barriers properly as planned.

Reviewer 7:

The reviewer said that the gap between the modeling tools and cell design for the battery develops is addressed.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer said that roughly hundred fold acceleration of the calculation was achieved and that some samples made tested and simulated well.

The reviewer said that the project obtained basic physical parameters of components and that the method for gathering data for parameters and deciding where emphasis will yield value in the final cell.

The reviewer said that the project subjected cells to abuse tests and that Cu foils fail before separator — noting that the foil failure was modeled on only single pairs, not full cells. The reviewer said that the project can calculate how resistance changes as crush proceeds and that the model predicted results well.

The reviewer said that the result is an area to avoid in design and then a measure of error in the good region.

Reviewer 2:

The reviewer said that, given its demonstrated huge speed-up in simulation times with minimal accuracy degradation, this breakthrough reduced order method has the potential to make LIB system modeling and simulation much more tractable. Regarding the parameter identification methodology, the reviewer did not see any indication that temperature-dependence was accounted for.

Reviewer 3:
The reviewer said that the accomplishments for Task 1 seem good and need to focus on uncertainty propagation.

The reviewer said that the accomplishments for Task 2 seem good and that they would quickly move on to realistic loading conditions.

Reviewer 4:
The reviewer said that the project is on target, and referred to a previous comment. The reviewer would also prefer that next time some more details are included on the ongoing project status PowerPoint slides.

Reviewer 5:
The reviewer said that substantial progress has been made towards achieving the target goals.

Reviewer 6:
The reviewer said that the contractor has achieved technical progress as promised.

Reviewer 7:
The reviewer said that the increased computational speed will make the model more acceptable.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that the project demonstrated very good coordination among the key players and contributors to achieve the mission critical needs.

Reviewer 2:
The reviewer said that it appears the members of this project have good collaboration and the project leverages experiments and developments in other CAEBAT projects efforts.

Reviewer 3:
The reviewer said that the project is inherently collaborative with several other collaborators outside the funding circle from industry.

Reviewer 4:
The reviewer said that the collaboration is all national laboratories and that it might be useful to integrate some university materials researchers. The reviewer was not sure why the project is using LS-Dyna (commercial version of Dyna) when it could get DOE version Dyna3d or Paradyn. The reviewer asked if the automotive advisors are pushing for the team to use LS-Dyna. The reviewer said that another good software that could model the liquid electrolyte would be CTH out of SNL and that maybe collaborating with someone at Lawrence Livermore National Laboratory would provide you with the source to Dyna and more development possibility.

Reviewer 5:
They reviewer said that hopefully all famous world universities and laboratories and corporations have been explored (benchmarking).

Reviewer 6:
The reviewer said that the testing collaboration with the national labs provide more meaningful models.

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.

Reviewer 1:
The reviewer said that the future research seems fine and that the reviewer would quickly move past the static tests and move onto to dynamic testing that is more realistic of the actual loading. The reviewer said that this is also what explicit FEA schemes were designed for and that the project's current loading conditions could be simulated with transient implicit schemes.

The reviewer would also like the project to go back and get a better hold of uncertainty in Task 1as there is no way the uncertainty can be on the order of the diffusion.

Reviewer 2:
The reviewer said that the validation and publication of model information will be useful to the industry to accelerate battery development.

Reviewer 3:
The reviewer said that the future research plans are well planned.

Reviewer 4:
The reviewer said that plans are appropriate and do-able and that the timing seems about right.

Reviewer 5:
The reviewer said that it is unclear if the model can cover automotive battery working temperature range. If yes, the reviewer asked if there are validation experiments to cover that range planned.

Reviewer 6:
The reviewer said that once modelling is completed, some statistical designed experiments should be completed. The reviewer referenced prior comments.

Reviewer 7:
The reviewer said that perhaps the future parameter identification research could consider temperature dependence.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said that this project does support the overall DOE objectives of petroleum displacement because it facilitates the usage of LIB systems (thus decreasing the size of any required petroleum-fueled power source) by further developing LIB modeling and simulation capability for design and analysis purposes.

Reviewer 2:
The reviewer said that this project is an integral part of efforts to develop validated modeling tools to accelerate development of batteries, in support of vehicle electrification R&D to reduce dependence on imported oil.

Reviewer 3:
The reviewer said that this could accelerate the development of safe effective cells for a low-cost electric vehicle and that helps displace petroleum.

Reviewer 4:
The reviewer said that accelerated battery development will increase the probability of an EV acceptance.

Reviewer 5:
The reviewer said that the material R&D is focused on characterizing the next gen cathode materials to improve energy efficiency of batteries and that this supports the DOE petroleum objectives.

Reviewer 6:
The reviewer said that it will help DOE to reduce time for development and make more competitive.

Reviewer 7:
The reviewer said yes, the project supports the DOE 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 said that continuing funding is important for statistically designed experiments.

Reviewer 2:
The reviewer said that the contractor appears to have sufficient resources in conducting the proposed work.

Reviewer 3:
The reviewer said that the funding seems roughly right for the task at hand and that the project is making good progress at this funding level.

Reviewer 4:
The reviewer said that resources seem adequate.

Reviewer 5:
The reviewer said that the laboratory capabilities and resources are sufficient.

Presentation Number: es299
Presentation Title: Microstructure Characterization and Modeling for Improved Electrode Design
Principal Investigator: Kandler Smith (National Renewable Energy Laboratory)

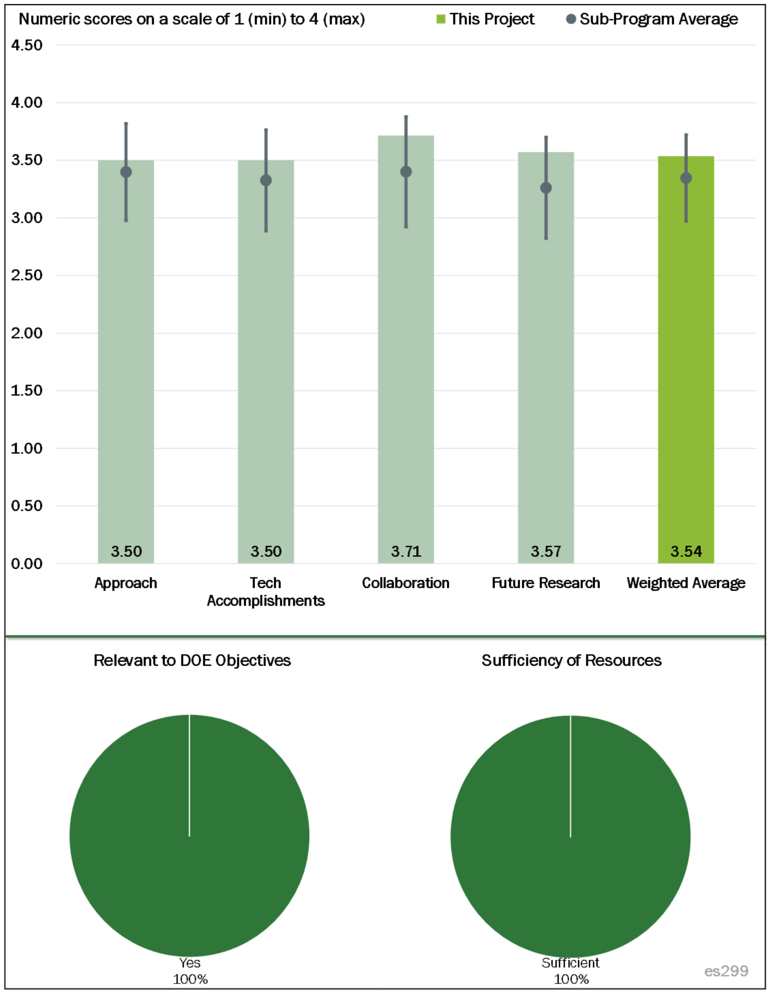

Figure 3-56 - Presentation Number: es299 Presentation Title: Microstructure Characterization and Modeling for Improved Electrode Design Principal Investigator: Kandler Smith (National Renewable Energy Laboratory)

Presenter

Kandler Smith, National Renewable Energy Laboratory

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that the approach appears to be well conceived, logical, and suitable for the associated objectives.

Reviewer 2:

The reviewer said that the lack of predictive capability of electrode design has been addressed to some extent and that validation results shows less than 10% error between test and simulation.

Reviewer 3:

The reviewer said that all major principles are being well modeled. However, the reviewer noted that there are some ambiguities around electrodes that expand and the impact of electrolyte, how well are these modeled in their entirety.

Reviewer 4:

The reviewer said that the project appears to have addressed technical barriers properly as planned and questioned if the project started in October 2015 or 2016. The reviewer said that it claimed to be 2016 on slides and in briefing, but that 3 years' project support was started in October 2015.

Reviewer 5:

The reviewer said that the approach seems fine and that the reviewer would like to see more details on direct numerical simulation (DNS) simulation. The reviewer express uncertainty about what the justification is for a DNS simulation. The reviewer asked if the PI expects a lot of mixing. The reviewer suspected these are pretty diffuse flows and DNS might be a little over kill. However, all the physics can be captured with DNS, which is good.

Reviewer 6:
The reviewer questioned, in reference to Slide 17, how sensitive the model is to reduce variation in particle size statistically and how that will affect battery performance. The reviewer said that hopefully status of detailed tomography work will be discussed in future.

The reviewer questioned, in reference to Slide 9, how fragility will be addressed. The reviewer noted that more porosity better capacity but more fragile.

Reviewer 7:
The reviewer said that the microstructure characterization and modeling is very essential for reliable cell modeling.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer said that substantial progress has been made to address the project goals and that microstructure analysis helps to simulate the electrode properties effectively. The reviewer said that one of the key question is: How to characterize binder properties and their strength and failure mechanisms?

Reviewer 2:
The reviewer said that the project completed characterization of a few electrodes, developed the models, started process of applying the tools to the data, and added non-sphere models, which is clearly better.

The reviewer said that the project team is confident the microstructures are valid for other non-expanding electrodes.

Reviewer 3:
The reviewer said that the accomplishments seem good and that the reviewer would like to see some more explanation for the phenomena the project is seeing. The reviewer referenced Slide 14 and questioned why there is a maximum, but the team is fitting a straight line.

Reviewer 4:
The reviewer said that the contractor has achieved reasonable technical progress as planned.

Reviewer 5:
The reviewer said that the project is on target.

Reviewer 6:
The reviewer said that the accomplishment of microstructure modeling will help with overall model.

Reviewer 7:
The reviewer said that it does not appear that the temperature-dependence of the microstructure characterization and model parameters has been considered.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that the collaboration seems good and the reviewer expressed surprise there is no one at a U.S. university doing nanoscale tomography. The reviewer said that maybe for future studies the project team should find a U.S. collaborator.

Reviewer 2:
The reviewer said that by collaborating with academia and other research laboratories enhances the knowledge sharing and new findings.

Reviewer 3:
The reviewer said that it is a collaborative project but also includes London. The reviewer expressed surprised there is not more collaboration though given the number of people working in this area.

Reviewer 4:
The reviewer said that the contractor has achieved reasonable technical progress within about 1.5 years and noted that the percent completion is claimed to be 45%. The reviewer questioned if another 55% of the work will be accomplished in less than 1.5 years.

Reviewer 5:
The reviewer said that the collaboration with other national laboratories and university will lead to better understanding of the model.

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.

Reviewer 1:
The reviewer said that the future research proposal covers broad details of meso-scale modeling approach, electrode effectiveness, and validation plans.

Reviewer 2:
The reviewer said that the proposed future work is good and that the model may provide more benefit to users if it can address the statistical nature of microstructures in life.

Reviewer 3:
The reviewer said that the future work seem good and the reviewer would focus on validation. The reviewer would also like the project team to look into a different mesh for the DNS simulation. The reviewer said that the project team should be able to use a non-structured mesh to better resolve shape and actually save on number of mesh cells.

Reviewer 4:
The reviewer said that the future work is the logical things to do and follows the plan.

Reviewer 5:
The reviewer said that direct measurement of effective properties is planned.

Reviewer 6:
The reviewer said that perhaps the future microstructure characterization and model parameter research could consider temperature dependence.

Reviewer 7:
The reviewer referenced a previous comment.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said that characterizing the electrodes and other materials in the battery is very critical to support the DOE petroleum displacement objectives. The reviewer said that the authors clearly identifies the necessary steps with supporting research in that direction.

Reviewer 2:
The reviewer said that this project is an integral part of efforts to develop validated modeling tools to accelerate development of batteries, in support of vehicle electrification R&D to reduce dependence on imported oil.

Reviewer 3:
The reviewer said definitely and if it succeeds will help speed penetration of battery electric vehicles (BEVs) and reduce gasoline use. The reviewer said that the aim of predictive (not simulation after the fact) capability is excellent.

Reviewer 4:
The reviewer said that this project does support the overall DOE objectives of petroleum displacement because it facilitates the usage of LIB systems (thus decreasing the size of any required petroleum-fueled power source) by further developing LIB modeling and simulation capability for design and analysis purposes.

Reviewer 5:
The reviewer said yes, this supports the DOE mission and focuses on understanding the electrolyte.

Reviewer 6:
The reviewer said that the model will accelerate the battery development and may reduce the total cost.

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 all of the major milestones are satisfied successfully.

Reviewer 2:
The reviewer said that the contractor appears to have sufficient resources in conducting the proposed work.

Reviewer 3:
The reviewer said that the project seems to have what they need and the progress is about appropriate.

Reviewer 4:
The reviewer said that the resources seem sufficient and that the reviewer is unsure what high-performance computing (HPC) resources are available.

Reviewer 5:
The reviewer said yes, and referenced a prior comment. The reviewer said that statically designed experiments after modelling completed will be valuable (Taguchi fractional factorial with small set of experiments).

Reviewer 6:
The reviewer said that the laboratory resources and the university capabilities are sufficient for the success of the model.

Presentation Number: es300
Presentation Title: Enhancement and Deployment of VIBE, the Open Architecture Software (OAS) Environment
Principal Investigator: John Turner (Oak Ridge National Laboratory)

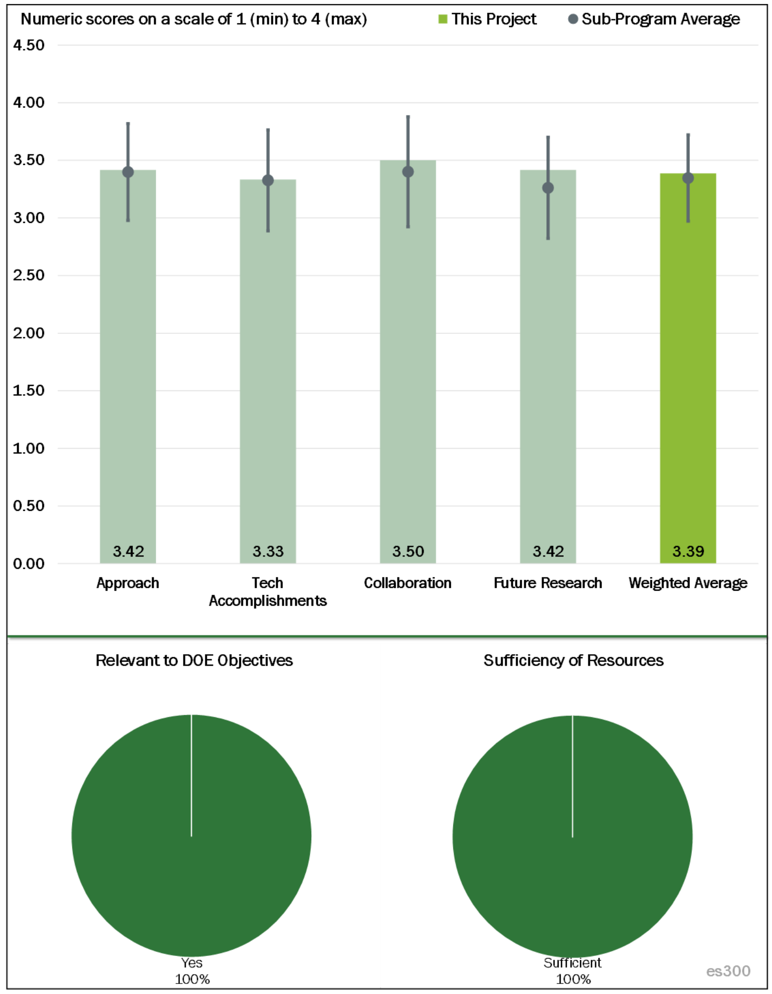

Figure 3-57 - Presentation Number: es300 Presentation Title: Enhancement and Deployment of VIBE, the Open Architecture Software (OAS) Environment Principal Investigator: John Turner (Oak Ridge National Laboratory)

Presenter
Srikanth Allu, Oak Ridge National Laboratory

Reviewer Sample Size
A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer said that it is well planned.

Reviewer 2:
The reviewer said that the project appears to be well designed and addressed technical barriers properly as planned.

Reviewer 3:
The reviewer said that the approach is valid even though the slides on approach really are more about implementation that the actual approach which is to develop and validate physics based software that predicts the performance and abuse tolerance of cells.

Reviewer 4:
The reviewer said that the approach seems okay but the reviewer was unsure what models the project is using, and asked if it is all explicit FEA. The reviewer will assume it is all explicit FEA. The reviewer saw a LS-Dyna simulation in slides and questioned if the understood approach is to develop a python wrapper to launch the FEA codes.

Reviewer 5:
The reviewer said that the virtual integrated software will be more user-friendly than the current software tools.

Reviewer 6:
The reviewer said that, regarding “upscaling effective properties from microstructure simulation,” the reviewer did not see the effects of temperature being considered.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer said that the reduction of simulation time by approximately 50% is impressive.

Reviewer 2:
The reviewer said that the project improved the execution time significantly.

Reviewer 3:
The reviewer said that the accomplishments seem good and that the project is able to run some different simulation; however, the different types of simulations were not specified. The reviewer said that it was also not clear if the python wrapper parses the output.

The reviewer said that it seems hard to believe that an explicit heat transfer model is the bottleneck in the simulation. The reviewer saw that the electrical model is actually the limiting case. The reviewer asked what the mesh looks like for these. Again, the reviewer noted, no details on the modeling approach so the reviewer is assuming explicit FEA.

The reviewer said to quickly move past these static indentation tests and move on to higher strain rates that are more representative of actual failure.

Reviewer 4:
The reviewer said that the project demonstrated the feasibility to construct three-dimensional (3D) meshes from electrodes using micro-tomography and that good correlation was established with mechanical indentation test.

The reviewer said that the effect of binder distribution and what adhesive mechanisms is not very clear.

Reviewer 5:
The reviewer said that the contractor has achieved reasonable technical progress as planned.

Reviewer 6:
The reviewer said that the milestone on shorts seems like a good goal but it is not clear how well it simulates real data.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that the collaboration with other national laboratories, Ford, and NHTSA will result in a more meaningful development tool.

Reviewer 2:
The reviewer said that the members of this project have good collaboration with each other and the project leverages experiments and developments in other CAEBAT projects efforts.

Reviewer 3:
The reviewer said that the project is collaborating in a sense in team but not a great deal outside it seems.

Reviewer 4:
The reviewer said that the collaborators are all national laboratories and that it may be worthwhile to collaborate with university on how to speed up heat transfer model. The reviewer said that this should not be that slow and noted again, that it is missing lots of details about mesh and scheme.

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.

Reviewer 1:
The reviewer said that the authors cover a broad range of future research from reduced order modeling to scalability of properties.

Reviewer 2:
The reviewer said that fine tuning of the model and reduced order of modeling is planned.

Reviewer 3:
The reviewer said that the future work are good things to work on, but that even better would be if the software could detect stiff problems and drop out of the reduced order model and go to the full model automatically.

Reviewer 4:
The reviewer asked does the proposed understanding of the influence of temperature variations during dynamic discharge of battery module cover automotive battery working range.

Reviewer 5:
The reviewer would like to see some more details about heat transfer model and mesh. The reviewer thought a mesh study is in order if it has not been conducted and that this will be critical to resolving thermal gradients at indentation.

The reviewer said that it would also be worthwhile to maybe write a python graphical user interface (GUI) to run these simulation and culminate results. The reviewer said that nice plotting can be done with python and this is idea of a wrapper is what python was made for.

The reviewer also said it would be nice to see more details on message passing, sockets or files. The reviewer asked if the PI has the source to these FEA codes.

Reviewer 6:
The reviewer said that perhaps the influence of temperature can be considered for "upscaling effective properties under varying porosities and binder re-allocation."

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said that the simulation identifies many aspect of battery materials some of which cannot be determined from test and that this project aims to address some of those critical aspects and meet overall DOE objectives.

Reviewer 2:
The reviewer said that this project of enhancing the open architecture software (OAS) is an integral part of efforts to develop validated modeling tools to accelerate development of batteries, in support of vehicle electrification R&D to reduce dependence on imported oil.

Reviewer 3:
The reviewer said that this project does support the overall DOE objectives of petroleum displacement because it facilitates the usage of LIB systems (thus decreasing the size of any required petroleum-fueled power source) by further developing LIB modeling and simulation capability for design and analysis purposes.

Reviewer 4:
The reviewer said that being able to predict performance and abuse impacts would definitely help put EVs on the road.

Reviewer 5:
The reviewer said that this project supports the DOE mission and might be a little ahead of the other modeling efforts but very relevant.

Reviewer 6:
The reviewer said that the tool will reduce time to develop 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 said that the author has achieved milestones deliverables in a timely fashion.

Reviewer 2:
The reviewer said that the contractor appears to have sufficient resources in conducting the proposed work.

Reviewer 3:
The reviewer said that work is moving well and that there is no obvious wastage.

Reviewer 4:
The reviewer said that the laboratory testing and software development resources are sufficient.

Presentation Number: es301
Presentation Title: Experiments and Models for the Mechanical Behavior of Battery Materials
Principal Investigator: John Turner (Oak Ridge National Laboratory)

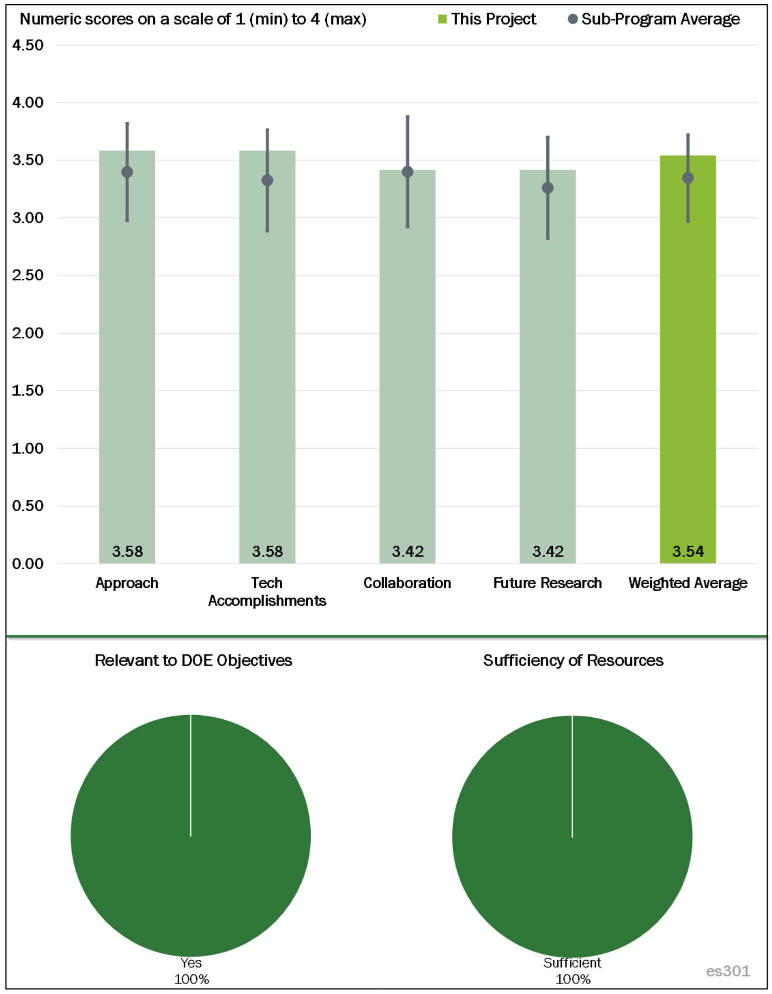

Figure 3-58 – Presentation Number: es301 Presentation Title: Experiments and Models for the Mechanical Behavior of Battery Materials Principal Investigator: John Turner (Oak Ridge National Laboratory)

Presenter

Sergiy Kalnaus, Oak Ridge National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer stated that the approach appeared to be well conceived, logical, and suitable for the associated objectives.

Reviewer 2:

The reviewer commented that a significant effort was made to understand the behavior of the separators which are a critical component of Li batteries. Three commercial separator models were evaluated and their performances compared in order to quantify the understandings. Differences in anisotropic behavior, yield strength and failure modes were demonstrated. Overall the reviewer noted that this was very well done.

Reviewer 3:

The reviewer noted that the modeling that was based on experimental testing will provide robust models.

Reviewer 4:

The reviewer stated that the project addressed technical barriers of insufficient understanding of the underlying physical phenomena that limit battery performance and safety, particularly the role of microstructure.

Reviewer 5:

The reviewer noted the presence of experiments and models with validation by temperature. Several sorts of separators were studied. While the project has intention to do parametric variation to try to capture the variation in real results, the methodology was not clear to the reviewer. The reviewer observed that one omission is ceramic fill which is a fairly common type and more tests of the penetration depth to failure were needed. These thoughts are offered more in aide of developing these methods. The reviewer concluded that this was a very well organized project.

Reviewer 6:

The reviewer said that the approach seemed fine. There were no real details on what type of modeling was being done; the reviewer guessed that it was molecular dynamics (MD). The reviewer questioned what software was being used, and were there details about pair potentials. The reviewer liked the approach of different strain rates. This is critical to get meaningful information out of the studies.

The reviewer would expect strain hardening from polymer-based separators. The reviewer suggested checking the simulations. The reviewer noted that when conduction explicit FEA simulations with solid elements, at least three elements are needed through the thickness. The reviewer recommended an independent mesh study. The reviewer noted that somewhere the units of g/mil were used, which is an unusual unit. One thing that would be interesting would be to determine residual stress from the FEA model.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer stated that excellent progress was achieved on the milestones. The project showed stress strain data on several major separators and two manufacturing types with very different failure modes. The reviewer noted that temperature resolved the data. The reviewer also noted the importance of ball indentation tests. Both postmortem and computed tomography investigation were used so the details and *in situ* results were seen. The reviewer also noted that the calendaring study achieved different porosity and microstructure and performance.

Reviewer 2:

The reviewer said that the strain distribution and failure were captured in MD simulation and presented in the report. The reviewer also noted that temperature dependent behavior of separators and critical short circuit condition were also shown. Overall the reviewer stated that the project demonstrated very good progress towards DOE goals.

Reviewer 3:

The reviewer commented that the contractor has achieved good accomplishments as planned.

Reviewer 4:

The reviewer said that separators and electrode mechanical properties were explored successfully.

Reviewer 5:

The reviewer said that accomplishments seemed good. The reviewer suggested focusing more on a material understanding of what was going on.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer observed that collaborating with DOE national laboratories and industry partner(s) was “a plus”.

Reviewer 2:

The reviewer commented that the members of this project have good collaboration with each other and the project leverages experiments and developments in other CAEBAT projects efforts.

Reviewer 3:

The reviewer noted the presence of both inter-partner collaboration with several partners but also collaboration outside the partnership. The reviewer stated that this seemed like “real” collaboration not just a chance conversation.

Reviewer 4:
The reviewer commented that collaboration within Consortium for Advanced Batteries Simulation (CABS) members and others was well practiced.

Reviewer 5:
The reviewer highlighted the fact that collaboration consisted mainly of DOE national laboratories with Ford. It might be worthwhile to collaborate with universities to understand polymer-based mechanics of materials.

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.

Reviewer 1:
The reviewer noted that future research considers some critical aspects such as other modes of cell deformation, electrodes testing at different temperature and strain rate sensitivity of separators. This research helps to understand the risk well and helps in finding a mitigation strategy.

Reviewer 2:
The reviewer stated that the conducted work and proposed research seemed to cover limited battery materials such as separators.

Reviewer 3:
The reviewer noted that proposed future work was planned to address the remaining challenges.

Reviewer 4:
The reviewer stated that the challenges are correct, only the statistical treatment of many simulations to match experiment is not well defined. Validation is critical and a good item in the list of future work to focus on.

Reviewer 5:
The reviewer suggested the need to look into strain hardening and non-linear material models.

Reviewer 6:
The reviewer commented that given the findings shown, one could assume that any thermal sensitivity associated with the “failure criteria for layered battery structure“ and “microstructure-based continuum model“ would be considered. Perhaps the “microstructure-based continuum model” could account for the bending moment as well.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that this project does support the overall DOE objectives of petroleum displacement because it facilitates the usage of LIB systems (thus decreasing the size of any required petroleum-fueled power source) by further developing LIB modeling and simulation capability for design and analysis purposes.

Reviewer 2:
The reviewer stated that better knowledge of all the components in a battery will achieve DOE the petroleum displacement objective(s).

Reviewer 3:
The reviewer said that this project of enhancing the OAS is an integral part of efforts to develop validated modeling tools to accelerate development of batteries, in support of vehicle electrification R&D.

Reviewer 4:
The reviewer simply said that separator failure is important in safety.

Reviewer 5:
The reviewer remarked that this activity accelerates cell development and may reduce the cost of 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 noted that the contractor appears to have sufficient resources in conducting the proposed work.

Reviewer 2:
The reviewer observed fairly efficient use of money, and noted that the project was not strained for cash.

Reviewer 3:
The reviewer commented that the national laboratories have sufficient funding and resources.

Presentation Number: es302
Presentation Title: Microstructure Imaging and Electrolyte Transport Property Measurements for Mathematical Modeling
Principal Investigator: Venkat Srinivasan (Argonne National Laboratory)

Presenter

Venkat Srinivasan, Argonne National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

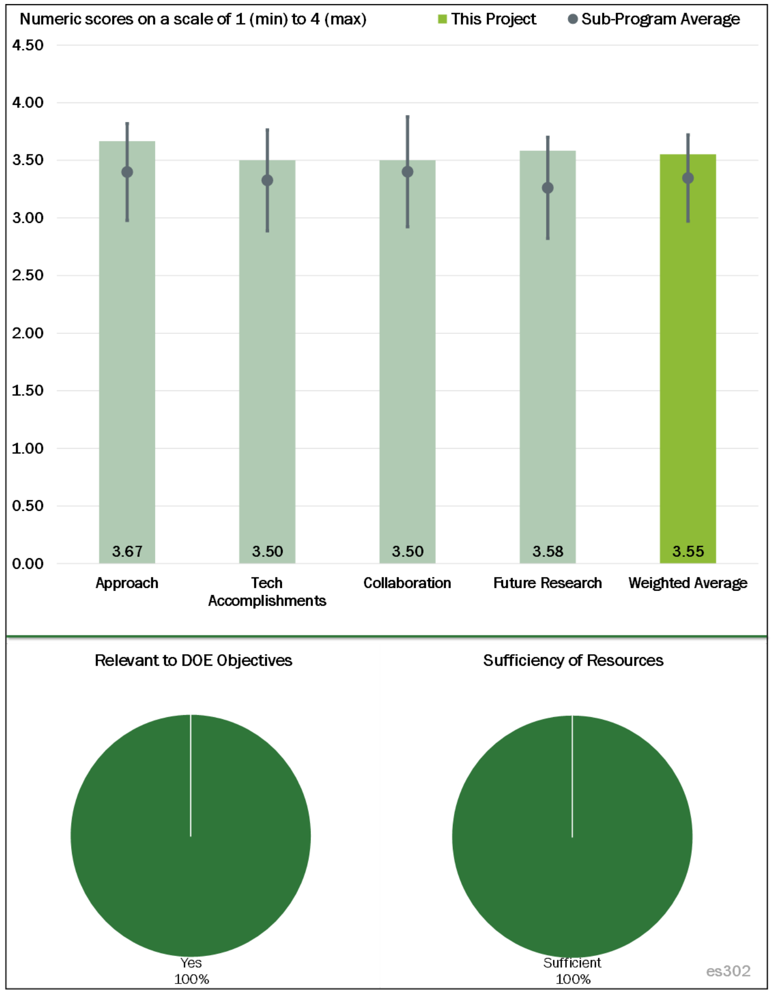

Figure 3-59 - Presentation Number: es302 Presentation Title: Microstructure Imaging and Electrolyte Transport Property Measurements for Mathematical Modeling Principal Investigator: Venkat Srinivasan (Argonne National Laboratory)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer remarked that the project aims to deliver accurate input data for the CAEBAT teams which is an essential element of successful analysis.

Reviewer 2:

The reviewer stated that the technical approach has been successful in providing electrode microstructure data and generating surface meshes and concentration-dependent electrolyte transport property to support battery modeling and simulation (M&S) work.

Reviewer 3:

The reviewer commented that this activity provides accurate simulation data, which are needed for robust model development.

Reviewer 4:

The reviewer said that the approach for obtaining “electrode microstructure data” under realistic conditions is valuable for increasing the accuracy of the CAEBAT input parameters and resulting modeling predictions.

Reviewer 5:

The reviewer remarked that the project seemed to be making the right measurements to serve the team. Setting a range of specified pressure for measurement conditions would be better.

Reviewer 6:

The reviewer noted that the approach seems good. No details were given on the modeling approach in terms of size of domain and time step, etc. The reviewer asked if diffusion is through a medium being calculated or just self-diffusion. These details should be provided. Details on boundary conditions would also be useful. The reviewer asked if these are temperature driven or gradient driven, and what are the initial conditions. That being said, the reviewer further noted that this is a useful study. These quantities are necessary for the FEA models that have been presented alongside this presentation.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer noted that very good progress has been made to capture the electrodes in real battery environment settings. Construction of electrode regions from TEM images adds more value in CAEBAT simulations.

Reviewer 2:

The reviewer said that the technical accomplishments and progress achieved were as planned.

Reviewer 3:

The reviewer noted that the project measured electrode internal structure wet and dry (and noted changes). The reviewer assessed this to be a very good technique. The reviewer also said that electrolyte diffusion and convection properties were measured and transport coefficients were generated. The reviewer observed that a checkpoint with known literature values was used. The project also showed ion pairing that lowers conductivity even at lower concentration. The reviewer also remarked on seeing multiple ways to get transport numbers which is very valuable.

Reviewer 4:

The reviewer stated that the accomplishments were okay. The project started in 2015 and the reviewer expected some more results by now. However, the results that were presented were good.

Reviewer 5:

The reviewer noted that the project produced electrolyte transport and electrode properties.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer commented that the collaboration among CABS and other institutions is excellent.

Reviewer 2:

The reviewer stated that the members of this project have good collaboration with each other and the project provided useful experimental data to support other CAEBAT projects efforts.

Reviewer 3:

The reviewer noted that the project worked with several partners, also with PNNL outside the group, but with a big group, this will suffice.

Reviewer 4:

The reviewer was not sure what CD-adapco was providing but they should provide some code development. If not, the reviewer would recommend changing the approach. These diffusion coefficients could be obtained using a molecular dynamic approach. The reviewer inquired if this is what was being using at the beginning. The reviewer further noted a lack of model information. This seems to be a common theme across all presentations. The reviewer suggested collaborating with a DOE laboratory that develops MD software; SNL's Large-scale Atomic/Molecular Massively Parallel Simulator (LAAMPS) for example. This will also resolve the ion pairing. Once the diffusion that length scale is understood then work can be done on the continuum diffusion problem.

Reviewer 5:

The reviewer stated that a lack of industry partner was seen in this project. Industry partners brings unique values to R&D from a customer point of view. The reviewer stated that the software vendor represents a good collaboration in developing robust software.

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.

Reviewer 1:

The reviewer observed the presence of logically planned future research.

Reviewer 2:

The reviewer commented that, if moving smoothly, the proposed research will make the project be conducted successful.

Reviewer 3:

The reviewer noted that appropriate plans were presented; for example, diffusivity as a function of concentration and temperature. The epoxy filled imaging versus wet tomography is a valuable plan. The reviewer said that cycled electrodes will also be illuminating.

Reviewer 4:

The reviewer suggested doing a microscale MD simulation and then working on continuum level diffusion.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer said that all the work in this project is relevant to DOE objectives of petroleum displacement.

Reviewer 2:

The reviewer stated that this project is relevant to DOE objectives and it can provide accurate simulation input data for CAEBAT teams, enabling construction of accurate models to guide cost and performance optimizations.

Reviewer 3:

The reviewer remarked that, yes, the project supported overall DOE objectives. The reviewer commented that solving the diffusion problem would be necessary for FEA work.

Reviewer 4:

The reviewer stated that the models will accelerate the battery development cycle.

Reviewer 5:

The reviewer noted that this project does support the overall DOE objectives of petroleum displacement because it facilitates the usage of LIB systems (thus decreasing the size of any required petroleum-fueled power source) by further developing LIB modeling and simulation capability for design and analysis purposes.

Reviewer 6:

The reviewer commented that, without good input data, the simulators have no chance. The simulation work will help with safety and cost.

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 funding and resources are sufficient.

Reviewer 2:

The reviewer commented that the project may be successfully accomplished if funding can be provided as budgeted.

Reviewer 3:

The reviewer stated that this seems to be good work and not simple work. If less funding must be given, do not trim this project much. Otherwise, the project data will be impacted. A much better solution would be to keep funding and ask for more variation as a function of other variables.

Reviewer 4:

The reviewer noted that the project will need HPC resources for MD simulations.

Presentation Number: es303
Presentation Title: Exploring How Electrode Structure Affects Electrode-Scale Properties Using 3D Mesoscale Simulations
Principal Investigator: Scott Roberts (Sandia National Laboratories)

Presenter
Scott Roberts, Sandia National Laboratories

Reviewer Sample Size
A total of six reviewers evaluated this project.

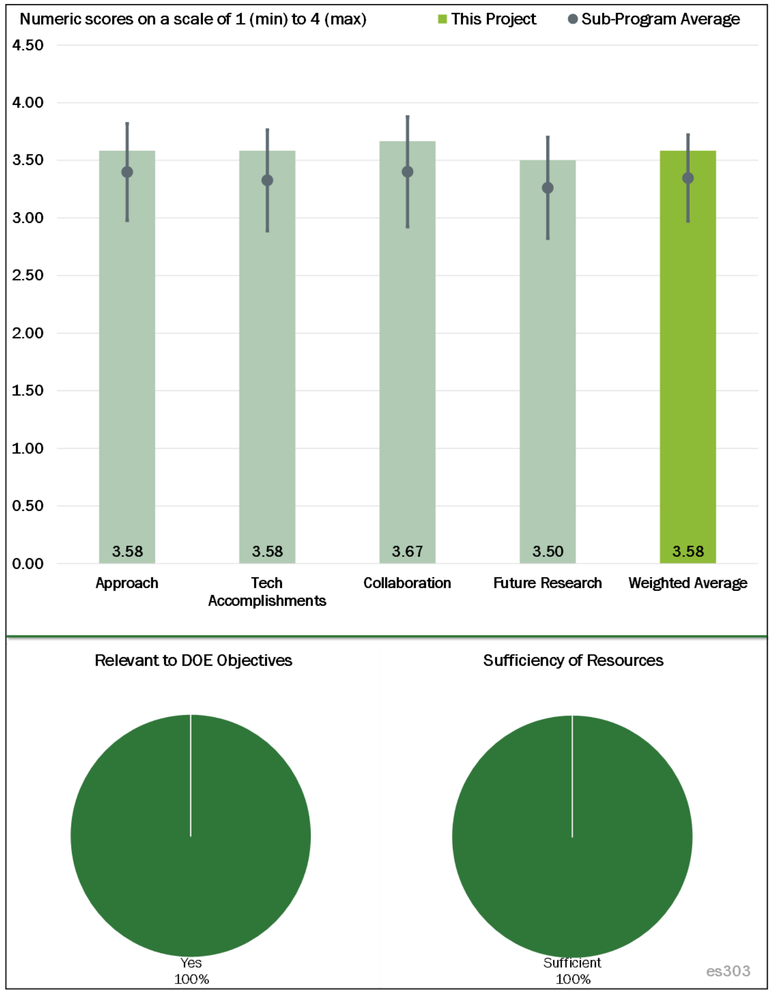

Figure 3-60 - Presentation Number: es303 Presentation Title: Exploring How Electrode Structure Affects Electrode-Scale Properties Using 3D Mesoscale Simulations Principal Investigator: Scott Roberts (Sandia National Laboratories)

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer stated that the project had a well-planned approach to capture the tasks.

Reviewer 2:
The reviewer noted that the battery scale-up simulation of abuse scenarios provides the basis for a safe battery.

Reviewer 3:
The reviewer said the approach appears to be well conceived, logical, and suitable for the associated objectives.

Reviewer 4:
The reviewer commented that the project aims to improve the ability to assess battery response to abuse scenarios computationally, enabling many parametric computer tests rather than expensive and dangerous experiments through the creation and application of microscale (particle-scale) electrode simulation. It is an integral effort of CAEBAT effort.

Reviewer 5:
The reviewer stated that the model methods are good, and that intent to run fast with low deviation from real electrode was good too. The addition of binder is a good thing as it is often ignored and plays a role mechanically and in the transport of ions.

Reviewer 6:
The reviewer said that the approach seems great. The reviewer liked the mesh. The reviewer remarked that this was much better than other approaches presented. The reviewer suggested collaborating with other projects on mesh strategies. The reviewer's only concerns were whether surface tension was considered during

solidification of secondary phases. The reviewer also questioned where the properties of secondary phases were being obtained from. Combining this with amorphous can result in some inconsistent properties.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer remarked that the accomplishments presented were great. Keep going on the same trajectory. The mesh study was refreshing.

Reviewer 2:
The reviewer commented that demonstration of the 3D model of electrode work was successful.

Reviewer 3:
The reviewer noted that this project has achieved reasonable progress and demonstrated microstructure simulations of a NMC cathode, including a manufactured representation of active binder phase.

Reviewer 4:
The reviewer that good milestone progress had been achieved. The project has validated convergence in its NMC sample. The project verified the reduction in resolution does not cause meaningful uncertainty at domains of 80 µ cube edges. Binder inclusion is important and the project developed some methods to test with validation.

Reviewer 5:
The reviewer noted that the effect of lithiation, porosity, and binder distribution on electrical conductivity was investigated. The reviewer questioned whether the thermal sensitivity of those relationships considered.

Reviewer 6:
The reviewer said that very high resolution X-ray tomography data provided good insight to inside the microstructure. Creating a high-quality microstructure mesh of cathode nano particles was very promising. The reviewer stated that one concern was when the author mentioned that particles are held together by constrained nodal rigid bodies. This will eliminate the free motion of particles and it will be hard to quantify the inter-particle forces. The reviewer asked what the effect is of damping and friction between particles.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted good collaboration between industry and academia along with other DOE laboratories.

Reviewer 2:
The reviewer stated that the project members appear to have good collaboration with six other institutions in developing the M&S efforts.

Reviewer 3:
The reviewer commented on the presence of collaboration inside and out of the group.

Reviewer 4:
The reviewer remarked that the project seemed to have everything under control.

Reviewer 5:
The reviewer said that collaboration among CABS members and other institutions was very efficient.

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.

Reviewer 1:
The reviewer said that the proposed future research is tailored to address millstones.

Reviewer 2:
The reviewer stated that in addition to efficient and robust microscale electrochemistry, inter-particle movement characterization will add more value to simulation capabilities.

Reviewer 3:
The reviewer noted that the only item not well covered is how variation across other chemistries will be handled.

Reviewer 4:
The reviewer commented that the only additional suggestion is to really nail down the properties of the secondary phase.

Reviewer 5:
The reviewer suggested determining the robustness and efficiency of microstructure of the electrodes.

Reviewer 6:
The reviewer remarked that perhaps the proposed "microscale simulations of coupled electrochemical-mechanical performance of NMC," and predictions of "electrode swelling during operation" can be performed in such a way that temperature-dependence is considered.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that all the efforts support the DOE objectives.

Reviewer 2:
The reviewer said that this project addresses DOE/VTO objectives of promoting vehicle electrification by developing microscale (particle-scale) electrode simulations to support CAEBAT.

Reviewer 3:
The reviewer commented that the simulations envisioned are going to be helpful in terms of speed to market, cost, and safety. All of these aspects are important to the objective of more BEVs and PHEVs.

Reviewer 4:
The reviewer said that the model will accelerate the battery development and reduce cost.

Reviewer 5:
The reviewer stated that this project does support the overall DOE objectives of petroleum displacement because it facilitates the usage of LIB systems (thus decreasing the size of any required petroleum-fueled power source) by further developing LIB modeling and simulation capability for design and analysis purposes.

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 contractor appears to have sufficient resources to conduct the proposed research.

Reviewer 2:
The reviewer noted that the laboratory funding and resources are sufficient.

Reviewer 3:
The reviewer stated that the project needs more HPC time with these mesh sizes.

Presentation Number: es304
Presentation Title: Extreme Fast-Charge and Battery Cost Implications
Principal Investigator: Shabbir Ahmed (Argonne National Laboratory)

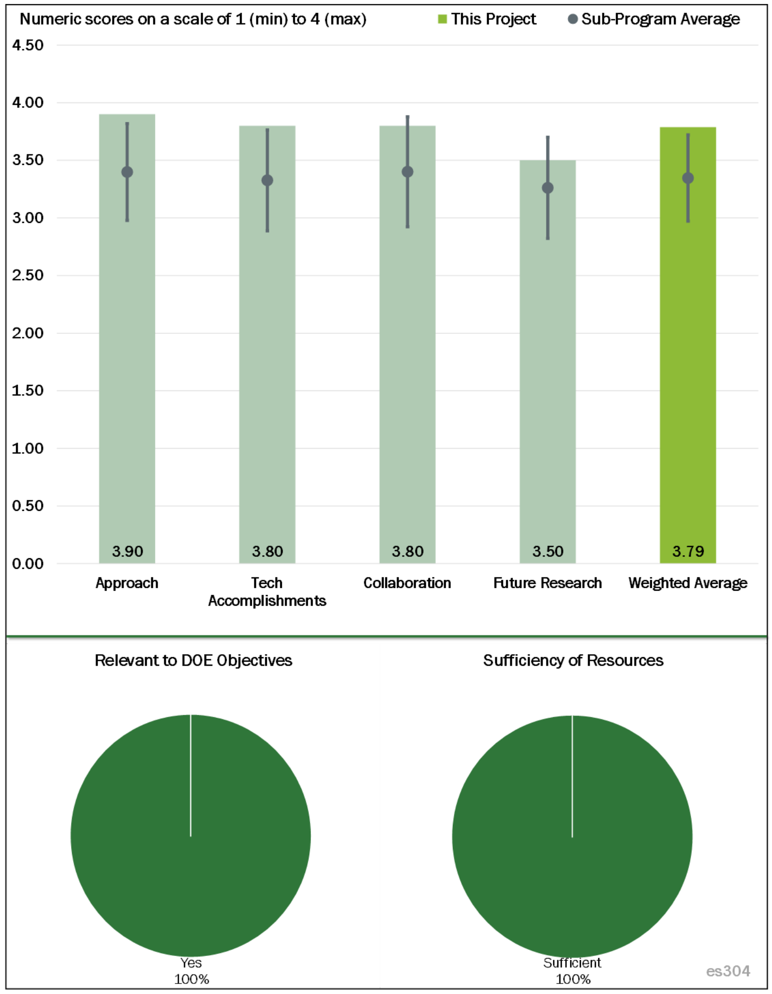

Figure 3-61 - Presentation Number: es304 Presentation Title: Extreme Fast-Charge and Battery Cost Implications Principal Investigator: Shabbir Ahmed (Argonne National Laboratory)

Presenter

Shabbir Ahmed, Argonne National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer asserted that this was a well-focused and well-designed project to identify technological barriers and to quantify their cost impacts for enabling extreme fast charging (XFC) of vehicle batteries. This study, using the BatPac cost model, took a comprehensive look at cell and system design factors to derive the cost implications of extreme fast charging.

Reviewer 2:

The reviewer stated that the project seemed well structured, feasible, and well integrated with related efforts.

Reviewer 3:

The reviewer commented that including industry, which must implement the work and sell it, is great.

Reviewer 4:

The reviewer noted that it was an excellent idea and a difficult task to organize fast charger stakeholders.

Reviewer 5:

The reviewer said that the modification and use of the existing BatPac model allows a very comparative baseline for this analysis.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer pointed out that the project made a comprehensive review of the various cell and system components that will be required to enable XFC. Then using a threshold current density that has been shown to trigger Li plating in BEV cells, the BatPac model was used to estimate the impacts on battery cost. As an aside, the reviewer noted that, of course, the estimation will be highly dependent on this threshold value and it needs to be verified in actual systems for corresponding cell chemistries and battery systems.

The reviewer noted that extensive calculations entailing charge limits as a function of anode thickness, lower resistance, and higher capacity electrodes along with effect of time to charge, charger limits, thermal considerations, etc., have been carefully assessed and this estimation can serve as a solid basis for future studies. Of course, availability of anodes having faster charging capability will eliminate most of the barriers highlighted here but it currently is a remote possibility (but at least the potential has been shown here). The reviewer found that overall, this was excellent work that will aid in DOE efforts to enable fast charging.

Reviewer 2:

The reviewer found this project to be well designed to support DOE goals. The original project scope was completed so progress was excellent.

Reviewer 3:

The reviewer stated that this project, one of a set, was intended to analyze the potential cost implications to a fast-charge capable battery pack. The project was successful in describing and quantifying the attributes that were assumed (and intuitive) to many people. The reviewer said that the study showed no bias to either acceptance or denial of technology adaptation (allowing for market based choices to prevail).

Reviewer 4:

The reviewer observed that the battery cost analysis based on the thin electrode architecture provided the estimate for a fast charging cell.

Reviewer 5:

The reviewer said that the project looked at thermal and design aspects and correctly found that thinner electrodes were needed; however, these electrodes increase the cost. Higher allowable current density helps a lot, as might be expected. This sets the goals well, but it does not say how to achieve them. Although that is not the objective here, it is okay. The reviewer pointed out that at the 4 mA/cm^2 limit, the mass increases and thickness drops faster than the heat generation, so no cooling is needed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer remarked that, by design, this collaboration was multi leveled. DOE structured a stakeholders' meeting at NREL and then subdivided the tasks into four projects while leveraging the work of all the laboratories toward the same goals. It was collaboration among the laboratories at its best.

Reviewer 2:

This reviewer opined that collaboration had lots of outsiders, but could not have been much better unless there had perhaps been an outside review of the final report prior to publishing it.

Reviewer 3:

The reviewer pronounced the participation of national laboratories and outside institutions in information exchange as successful.

Reviewer 4:
According to the reviewer, there was outstanding collaboration among various stakeholders, such as the national laboratories, government agencies, universities, and OEMs. Again, the only representatives missing are those from pack component makers, such as the ones dealing with high-voltage and high current.

Reviewer 5:
The reviewer noted that there appeared to be good collaboration within DOE, but outside of DOE exchanges seemed to be one way.

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.

Reviewer 1:
Even though the project has ended, the reviewer hoped that this study will be used to develop research work toward enabling fast-charging by DOE. This model can be easily adapted to other case scenarios to quantify the impact of a certain change in the assumed values due to cell and system change.

Reviewer 2:
The reviewed summed up future work as including fine tuning of the cost model, collecting data for thin electrodes, and running various scenarios.

Reviewer 3:
The reviewer said that this project was not intended for lengthy future analysis. It was short, to the point, and well defined. However, the reviewer had questions as to the effect of advanced materials, i.e., graphene anodes, which may have a considerable performance and cost basis for a successful system. The reviewer realized that some of these considerations will come as an output of the other projects but perhaps at that time may require further analysis in this BatPac environment.

Reviewer 4:
It was not clear to the reviewer about whether or not the project had ended. The reviewer remarked that overall it seemed like there was a good future plan, but it also seemed like the higher level project was over.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer offered that EVs capable of fast charging will make them more attractive to average customers and help in their proliferation to meet the DOE's overall goal of petroleum displacement.

Reviewer 2:
The reviewer found the project to be highly relevant. Fast charging puts BEVs on a par with ICEs for long-trip refueling and arguably better for refueling when time is no object. This matters to a good portion of customers.

Reviewer 3:
If successful with fast charging techniques, the EV will gain more popularity according to the reviewer.

Reviewer 4:
The reviewer said that by supporting increased use of electricity, the project would decrease petroleum usage.

Reviewer 5:
As this project has a definite objective to address barriers to EV acceptance and adoption, the reviewer commented that the general EV petroleum math applies to this project.

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

Reviewer 1:
The reviewer thought the amount of funds made available to the project was appropriate.

Reviewer 2:
The reviewer found the funding to be appropriate to the goals.

Reviewer 3:
The reviewer said that this project appears to have met its stated goals and objectives in a timely manner.

Reviewer 4:
The reviewer stated that funding was sufficient and the project is also complete.

Reviewer 5:
The reviewer commented that the laboratory resources are sufficient.

Presentation Number: es305
Presentation Title: Extreme Fast-Charging—A Battery Technology Gap Assessment
Principal Investigator: Ira Bloom (Argonne National Laboratory)

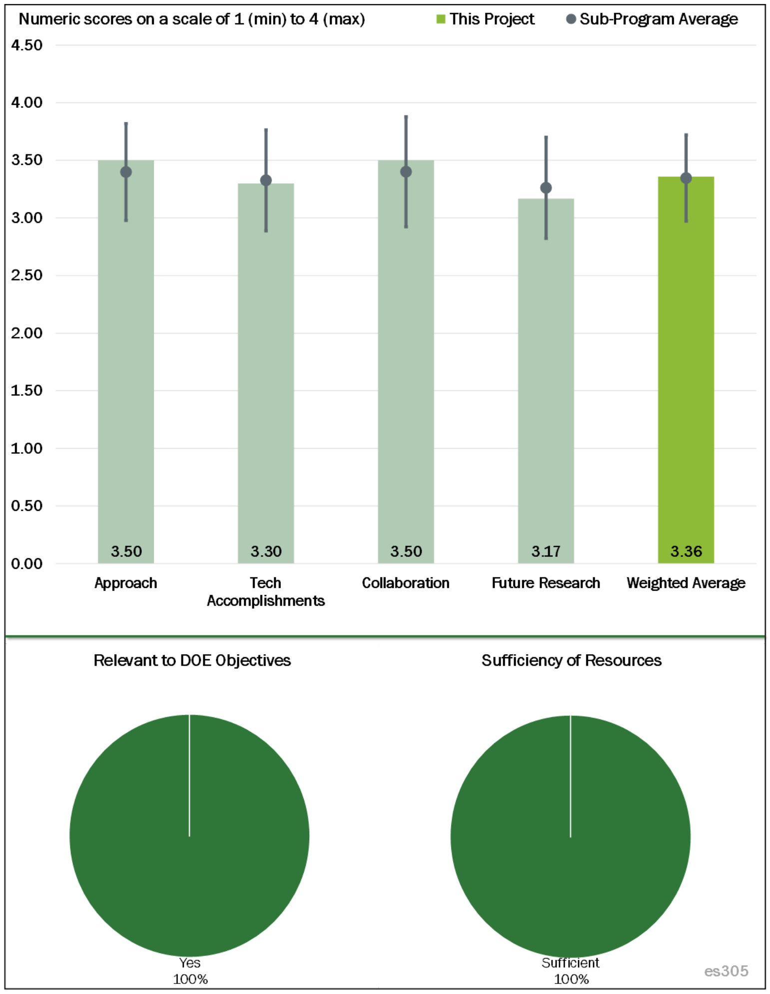

Figure 3-62 - Presentation Number: es305 Presentation Title: Extreme Fast-Charging—A Battery Technology Gap Assessment Principal Investigator: Ira Bloom (Argonne National Laboratory)

Presenter
Ira Bloom, Argonne National Laboratory

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that this was a highly focused task to identify technological and commercial gaps for XFC of vehicle batteries. The multi-laboratory team approach was an effective one in nailing down the various factors that are challenges to XFC.

Reviewer 2:
According to the reviewer, it is important to bring fast charging of batteries to fruition for widespread use of EVs. For this purpose, various factors that can impact cell performance and cost as well as define current limitation need to be identified. The reviewer said that this project takes a thorough approach to understand, identify, and come up with practical solutions for XFC.

Reviewer 3:
The reviewer asserted that the assessment of XFC is critical for the future direction for EV development.

Reviewer 4:
The reviewer stated that the project team used experts who identified the correct questions like design, heating, abuse impacts, heating, cost and so on via literature review.

Reviewer 5:
The reviewer thought that the work is mostly a literature review. The approach needs to be well defined, and the outcomes from the study—gaps and challenges and what direction DOE should take for the future—need to be considered.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer observed that the team had made a list of likely problems based on expertise and discussion. The list seems pretty complete.

Reviewer 2:
The reviewer said the technical accomplishments are satisfactory.

Reviewer 3:
The reviewer remarked that it is a good, extensive summary of many aspects that should be considered for XFC. It could have been much better if this study included quantitative analysis to some extent and showed practical examples. The summary was good but too generic. The reviewer was looking forward to seeing detailed findings in an upcoming publication in *J. Power Sources*.

Reviewer 4:
The reviewer summed up by saying that the assessment was complete and it provided a gap analysis. It also provided the list of components that will need a redesign for fast charging.

Reviewer 5:
The reviewer noted that the authors were able to comprehensively capture most of the items of relevance to XFC, such as at the cell level in a component as well as the pack level. However, some of the recommendations that were made, such as new anode and cathode materials that can withstand XFC need to developed, are redundant because battery developers have that goal in mind on a daily basis and these recommendations do not add anything new to what the developers are well aware of. The reviewer commented that statements about electrode and electrolyte designs for faster diffusion are also obvious.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that a good team of researchers was built for the study.

Reviewer 2:
The reviewer stated that the national laboratories collaborated to accomplish the objectives of the program.

Reviewer 3:
The reviewer commented that the analysis and summary are results of good collaboration among participants. Participation of industry could have made this effort more fruitful.

Reviewer 4:
The reviewer commented that there was inherent collaboration inside the group but it was not clear if there was all that much consulting outside the group.

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.

Reviewer 1:
The reviewer offered an opinion that we need to be very selective about topics for future research. Generic topics, such as electrodes and electrolytes with faster kinetics, are nothing new—people have been always exploring these—and unless someone comes back with a novel idea, such research should not be funded.

Reviewer 2:
The reviewer stated that the assessment is complete and there is no need for future activities.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated it definitely does. XFC capability will make EVs very attractive to the masses.

Reviewer 2:
The reviewer said the project is highly relevant to making EVs attractive and thus displacing petroleum.

Reviewer 3:
The reviewer responded yes, as the focus is on EVs.

Reviewer 4:
The reviewer found the project to be highly relevant to successful EV deployment.

Reviewer 5:
The reviewer observed that fast charging will help with determining the probability of success for EVs.

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

Reviewer 1:
The reviewer stated that sufficient funds were provided.

Reviewer 2:
The reviewer said that the project is complete so this question really does not apply.

Reviewer 3:
The reviewer stated that resources were sufficient.

Presentation Number: es306
Presentation Title: Thermal Implications for Extreme Fast Charge
Principal Investigator: Matthew Keyser (National Renewable Energy Laboratory)

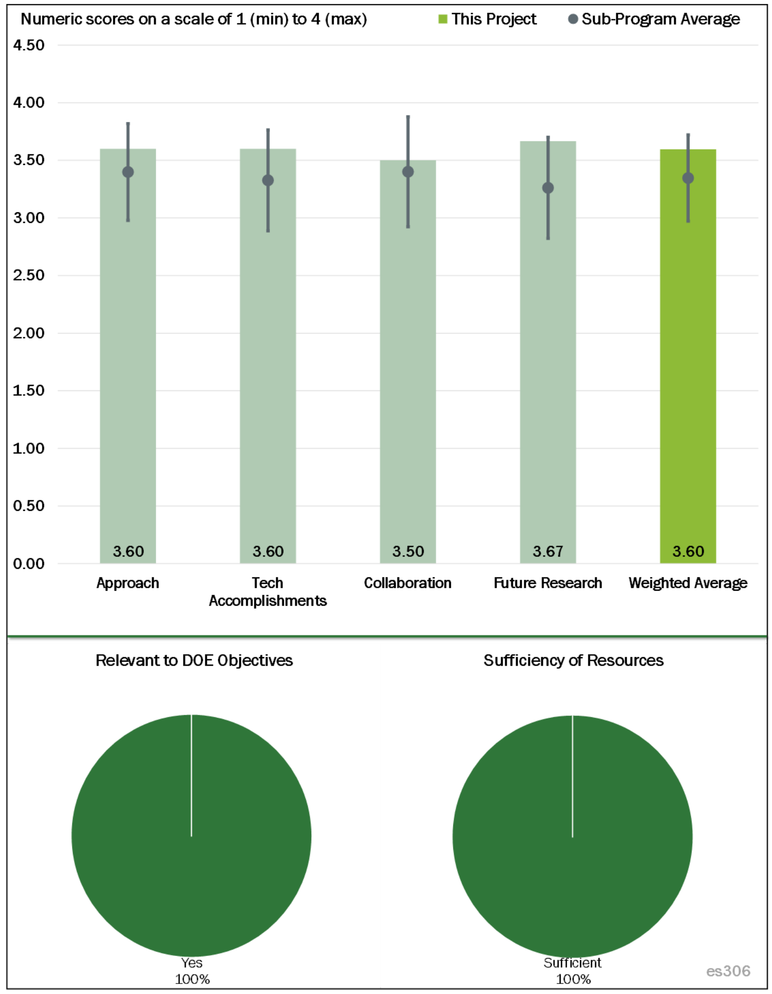

Figure 3-63 - Presentation Number: es306 Presentation Title: Thermal Implications for Extreme Fast Charge Principal Investigator: Matthew Keyser (National Renewable Energy Laboratory)

Presenter

Matthew Keyser, National Renewable Energy Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer acknowledged that the approach is very well designed. It takes into consideration all the factors (especially thermal) relevant to XFC charging, such as impact on durability, system management, and cost based on current cell and thermal management systems.

Reviewer 2:

According to the reviewer, to successfully deploy EVs that would be accepted by general users, fast-charging is extremely important. Finding and designing adequate chemistry and electrode structure that can withstand the XFS with minimal degradation should be done. Thermal aspects of cells and packs related to passing high current through the cells and packs are also to be considered because cell and pack temperature significantly affects their performance and life. In these respects, this project took appropriate approaches.

Reviewer 3:

The reviewer pointed out that the thermal characterization testing of the Li-ion cells provides the thermal management needed for a long life automotive battery system.

Reviewer 4:

The reviewer found the approach to be quite reasonable, considering the various aspects of the battery cell.

Reviewer 5:

The reviewer commented that heat transfer is a major problem with fast charging and this is appropriate work to identify the problems. As with others, stakeholder information should be gathered.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer asserted that excellent progress has been made in characterizing the current cells' thermal capabilities and limitations that will be highly valuable to develop future thermal requirements for XFC applications. Cells were characterized; various design options assessed with respect to their thermal footprints under various charge and discharge conditions and impact on heat efficiency; and assessments were made for future thermal systems.

It is an exhaustive study with valuable feedback that will be highly useful to DOE and other users.

Reviewer 2:
The reviewer commented that the project showed the need for higher heat venting in energy cells and what sort of property groupings might work. Based on the presented work, counter tab cell design works best. The reviewer emphatically stated that interconnects could add more heat than the cells.

Reviewer 3:
According to the reviewer, the progress was satisfactory with DOE goals met at the end of the project.

Reviewer 4:
The reviewer remarked that this project demonstrated good methodology to measure temperature variation during fast-charging and discharging. The cell temperature variation study according to cell geometry and tab structure is also useful. The suggestion from this study on practical capability of current thermal management system and desirable one is also good. The reviewer also liked the idea of additional cooling at the charging station so that the battery pack does not have to be overdesigned for XFC, which will not happen frequently.

Reviewer 5:
The reviewer observed that thermal characterization of various cells and batteries was successfully completed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that collaboration with cell and battery suppliers is very efficient in testing and finding design solutions.

Reviewer 2:
The reviewer noted that there are lots of different input groups and lots of discussion.

Reviewer 3:
The reviewer commented that collaboration with other laboratories was effective; however, OEMs need to be involved to understand the realistic approach to changing design of the electrodes.

Reviewer 4:
The study is the result of excellent collaborative work among key stakeholders involving national laboratories, universities, OEMs, and suppliers. Again, the reviewer was not sure that it included pack mechanical and electrical component suppliers who have a good stake from thermal system as well as high-voltage and high current points of view.

Reviewer 5:
The reviewer offered that participation from commercial sector would have made this effort much better.

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.

Reviewer 1:
The reviewer noted that the conclusions that stemmed from this study will deal with cell design, efficiency, size of thermal system, etc., which are valuable inputs for DOE for future program directions as well as for the battery community in general.

Reviewer 2:
The reviewer commented that innovative thermal designs and managements are explored.

Reviewer 3:
The reviewer said not applicable.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that development of an appropriate thermal system is a key requirement for the efficient operation of EVs capable of XFC. This project has contributed toward that goal.

Reviewer 2:
According to the reviewer, after safety, heat is likely the most relevant question. All of this supports consumer acceptance of EVs that displace gasoline and diesel fuel as fast as any method.

Reviewer 3:
The reviewer said yes. The project focused on improving reliability of future battery technology for EVs.

Reviewer 4:
The reviewer stated that this project showed, with some quantitative measures, the impact of fast charging on cell performance and suggested factors that needed consideration in order to make XFC a reality.

Reviewer 5:
The reviewer opined that the thermal management of Li-ion cells and batteries will meet the USABC life targets and make the systems affordable.

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

Reviewer 1:
The reviewer commented that the funding and resources are good enough for the testing, design, and supporting the development for new cells.

Reviewer 2:
The reviewer observed that the allocated resource was appropriate for this project.

Reviewer 3:
The reviewer stated that the project has also finished so its resources do not matter too much anymore.

Presentation Number: es307
Presentation Title: Discovery of High-Energy Lithium-Ion Battery Materials
Principal Investigator: Wei Tong (Lawrence Berkeley National Laboratory)

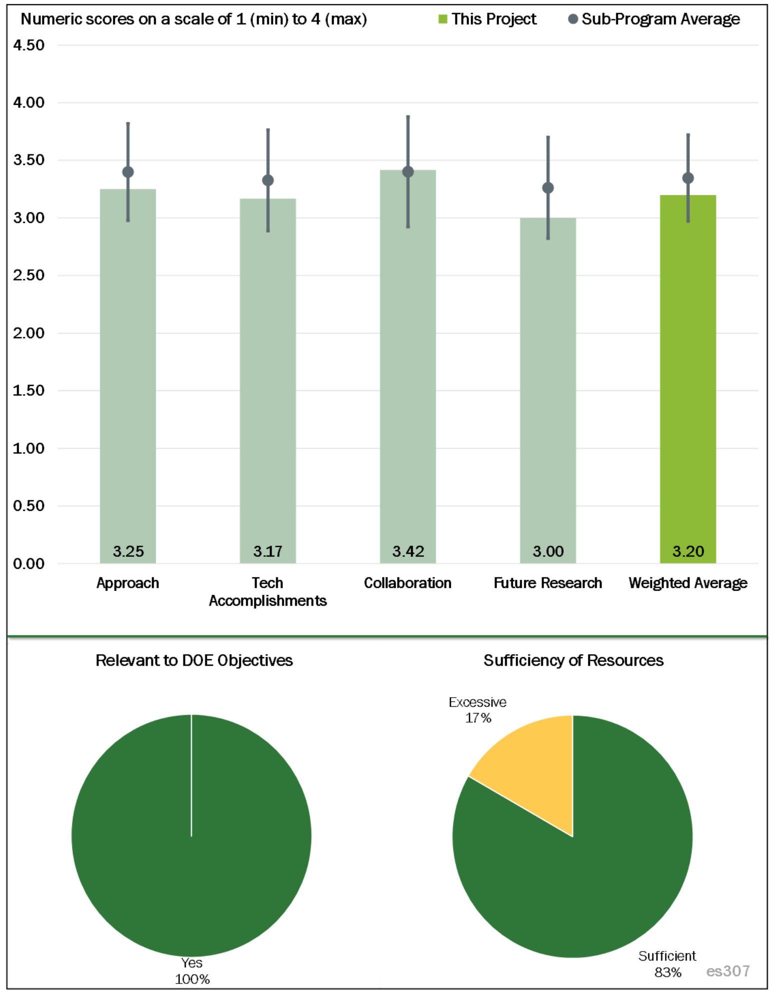

Figure 3-64 - Presentation Number: es307 Presentation Title: Discovery of High-Energy Lithium-Ion Battery Materials Principal Investigator: Wei Tong (Lawrence Berkeley National Laboratory)

Presenter

Wei Tong, Lawrence Berkeley National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that the objective here is to develop high-capacity cathode with greater than 200 mAh/g with minimal capacity and voltage fade exhibiting minimal capacity and voltage fade, from the Li-rich compositions in Li-Ni-O_2 chemical space, with the expectation to possibly utilize the Ni^{2+}/Ni^{4+} redox process for more than one Li per transition metal. These new cathode materials are expected to address the technical barriers of energy density, cycle life, and safety of the current Li-ion cells. The strategy here is to integrate a second transition metal on the first and second row in the Li-rich layered oxides to improve the structural stability and explore the participation of cationic and anionic redox activity and understand the correlation between composition and electrochemistry and the impact of transition metals on oxygen reactivity. The approach here is to utilize high-capacity Li-rich oxide cathodes, design compositions with Li excess and Ni^{2+} to Ni^{4+} redox along with a second transition metal, and investigate anionic O_2 reactivity using differential electrochemical mass spectrometry and advanced synchrotron core-level spectroscopic techniques. Li-rich LL oxides and Ni-rich NMC layered oxides have shown great promise for high capacity, which may be related to the O_2 redox. For the development of new compositions in this family of cathodes, it is essential to understand the role of transition metal substitution in the structural stability and O_2 redox, which this project is duly addressing. In this reviewer's opinion, this project is well designed, feasible and integrated with other DOE efforts.

Reviewer 2:

The approach is well thought out and outlined in a comprehensive fashion. The reviewer commented that the investigation into the impact of transition metals on O_2's involvement in capacity is highly relevant in today's push for higher capacity cathode materials.

Reviewer 3:

The reviewer stated that the project has great hypothesis-driven research and beautiful characterization and that this is a very relevant area of research. The characterization work is done with the end of improving the materials in mind.

Reviewer 4:

The reviewer noted that the work is systematic and focused on the project objectives.

Reviewer 5:

Significant voltage fade of Li- and Mn-rich layered oxides is well known and has been extensively studied. For these oxides to be adopted in practical Li-ion cells, the voltage fade issue should be thoroughly understood and solved. Even though current trend in high-capacity cathode development efforts is shifting from Li- and Mn-rich layered oxide to Ni-rich ones, there should be continuous research efforts to come up with cheaper, safer cathode materials with higher capacity.

Reviewer 6:

If the PI intends to utilize Ni2+ to 4+, the reviewer noted that coordinating with high-voltage electrolytes efforts may be required.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The team has achieved excellent progress to date in this reviewer's opinion. The investigators have demonstrated the impact of transition metal on O_2 reactivity in Li-rich layered oxides.

Reviewer 2:

The reviewer commented that the team has made good progress in designing new compounds in the Li-rich layered oxides to understand the role of transition metal on the structural stability and oxygen redox. Li-rich Ni-based oxides were designed and synthesized, lithium nickel manganese oxide (LNMO) and LNRO exhibited common features in crystal structure, morphology, and electrochemistry (discharge profile and capacity based on the number of Li). However, there was a distinct difference in charge profile observed in high-voltage region, evidenced by a 4.55V plateau for LNMO versus none for LNRO, which this reviewer finds fascinating. These compounds with commonality in structure and electrochemistry but distinct charge profile provide a platform to study the O_2 reactivity/behavior and potential impact of transition metal on oxygen reactivity in Li-rich layered oxides. In contrast to LNMO, where O_2 redox activity contributes to exceptionally high capacity and gas evolution, no O_2 activity was detected in LNRO. Instead, Ni and ruthenium (Ru) redox contribute to its high capacity, suggesting the potential impact of transition metal on the activation of O_2 redox. These finding are quite fascinating and are likely to result in new formulations with high capacity but without the complications of O_2 redox. Overall, the reviewer found the accomplishments notable, the progress measures well against the performance indicators, and the project is in tune with DOE goals.

Reviewer 3:

The reviewer stated that the project appears to be on track and meeting goals so far. This is an ambitious project, as these are complicated materials. The team is doing an excellent job bringing a variety of techniques to bear on the problem in this reviewer's opinion.

Reviewer 4:

Even though it may be a small quantity, the reviewer cautions that CO_2 and/or O_2 evolution warrants capacity fades with cycles. In the LMNO, the early charging at below 4.5V should be due to Mn(III) to Mn(IV), indicating a significant amount of Mn(III) corresponding to the oxygen deficiency. The reviewer stated that Ni alone cannot explain the low voltage capacity. The CO_2 evolution onset is about 4.0V, which indicates instability of the material even at low voltages. The claim of no changes in the Mn oxidation state is not convincing to this reviewer. RIXS is not clear for Mn. In the case of Ni, it is clear because it involves 2e changes, and is obviously more noticeable. The reviewer asked why the team did not collect the usual XANES for Mn Potassium (K)-edges.

Reviewer 5:
Some XAS study looks interesting, but this reviewer does not see any new findings in this study. The presenters claimed that Li-rich Ni-based oxides, LNMO and LNRO designed and synthesized, but these oxides have long been studied by many researchers, the results of which can be found in a Google search. Charge compensation mechanisms of LNMR and LNRO also have been studied and published, which is not much different from the results in this work. This reviewer had a difficult time understanding what the team is trying to achieve from this work. Ru might be an interesting element in that it could be oxidized/reduced between 6+ and 4+ state, but it is impossible to adopt Ru as a major component due to its extremely high cost.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
There are several useful collaborations, in this reviewer's opinion, within the DOE national laboratories and with university researchers in the material characterization through various sophisticated spectroscopic techniques, gas evolution studies and material development.

Reviewer 2:
The reviewer commented that the assembled team is outstanding, including many leaders in the field.

Reviewer 3:
The reviewer applauded the great coordination of a lot of collaborators who bring different skills to the project and recommended the team keep seeking out what you need to understand and improve these materials.

Reviewer 4:
This project includes a very nice group of collaborators. But considering the number of collaborators, the reviewer commented that the presented results are not as original and thorough as one would expect from such an excellent group of collaborators.

Reviewer 5:
There are too many collaborators in this reviewer's opinion.

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.

Reviewer 1:
The PI is proposing future work that is well-planned, comprehensive and has appropriate decision points. The reviewer noted that identification of the O_2 source by *in situ* DEMS through O_2 isotopic labeling is novel work.

Reviewer 2:
This reviewer likes that the PI is expanding studies on phase formation, etc. to better understand structure-property relationships. With the types of experiments you are doing, the PI is in a position to put these together.

Reviewer 3:
The reviewer said that appropriately, the future studies are to continue these studies to establish the phase transformation mechanism in LNRO and identify the limitation in LNRO rate and cycling performance; confirm the O_2 source in gaseous phases by *in situ* DEMS through O_2 isotopic labeling; further expand the studies on phase formation, crystal structure, and O_2 behaviors within LNRO composition space; and continue to explore other layered/rock-salt oxides to integrate Ni redox and other transition metals. The reviewer stated that these studies are consistent with the DOE goals of high specific energy, low-cost, and safe LIBs.

Reviewer 4:
Rather than emphasizing on charge storage on O_2, which would fade during charged storage by O_2 evolution/CO_2 evolution, the reviewer wondered why the team is not pursuing preventing decomposition.

Reviewer 5:
The reviewer said that from a fundamental point of view, crystallographic and electrochemical aspects of LNRO would be interesting. However, Ru cannot be utilized from a practical point of view, even though it would be a good model system. If the team wants to keep studying LNRO, then this reviewer would suggest a really fundamental and thorough study that could give a complete understanding of the material system. The reviewer suggested that the team move away from changing the composition and then performing a similar analysis and test that will result in only partial understanding. Or this reviewer strongly recommends focusing on other materials system as suggested in “Future Work” (other layered/rock-salt oxides).

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
In the sense that this project aims to develop high-capacity cathode materials, the reviewer finds that this project supports the overall DOE objectives.

Reviewer 2:
The reviewer said that for a widespread use of EVs and PHEVs, it is imperative that the LIBs are lightweight, compact, safe and of low-cost. The state of art materials are inadequate to fulfil these needs. High-energy density electrode materials are required to improve the specific energy for Li-ion cells and thus increase the range for the vehicle and reduce overall cost for the battery. The reviewer pointed out that the state of art cathode materials provide capacities of only 170 mAh/g, about half of the capacities possible from the carbon anodes. In this reviewer’s opinion, we need to explore new cathode materials, which the present project is duly addressing.

Reviewer 3:
The reviewer commented that the work is highly relevant to the overall DOE objectives.

Reviewer 4:
This reviewer said yes.

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

Reviewer 1:
The reviewer stated that the resources are adequate for the scope of the project.

Reviewer 2:
The reviewer commented that the resources are sufficient in order to successfully complete the effort in a timely manner.

Reviewer 3:

This reviewer stated there was too much garden variety and would prefer to see more focus.

Presentation Number: es309
Presentation Title: Electrode Materials Design and Failure Prediction
Principal Investigator: Venkat Srinivasan (Argonne National Laboratory)

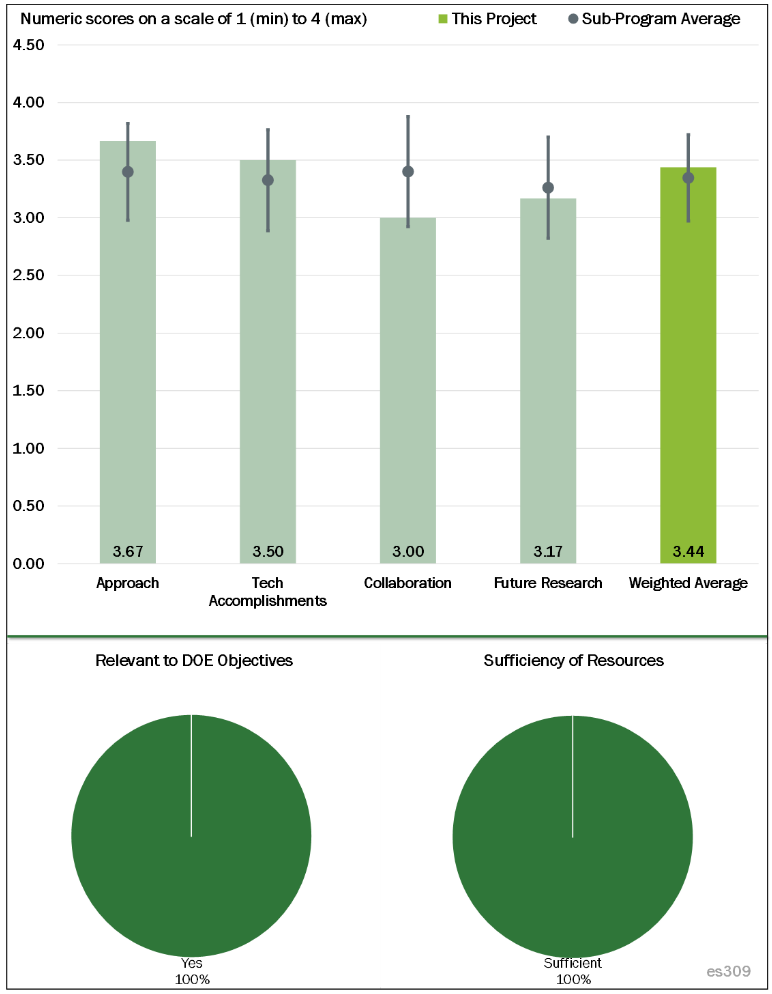

Figure 3-65 - Presentation Number: es309 Presentation Title: Electrode Materials Design and Failure Prediction Principal Investigator: Venkat Srinivasan (Argonne National Laboratory)

Presenter

Venkat Srinivasan, Argonne National Laboratory

Reviewer Sample Size

A total of three reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer said that this modeling approach is a good first step toward more realistic framework to deal with Li-metal dendrite formation and growth. It applies stress induced current distribution disparity and explains the propagation of such disparity into dendrite formation. It also includes plasticity to explain the modulus changes with the composition and the extent of dendrite growth. The reviewer noted that future incorporation of SEI properties and more mechanical stress field into the model could have some interesting results. It is still too early to tell if the approach is feasible or not, especially the difficulty in obtaining reliable data for the model and simulation. However, it is a good approach to begin with in this reviewer's opinion.

Reviewer 2:

The reviewer said that this coupled electro-chemical-mechanical modeling predicted the relationship between current density versus Li dendrite growth tendency. The computational predictions qualitatively agreed with experimental observations. The reviewer noted that the team presented the model assumptions very clearly. These assumptions gave the bounds for the modeling conclusions.

Reviewer 3:

The reviewer noted that the approach is general and flexible enough to build off of previous idealized analyses and can potentially grapple with more realistic systems, while allowing sufficient abstraction to derive design insights.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The model gave design maps that point to approaches to suppress dendrite growth. The reviewer stated that this is valuable to guide battery design with Li-metal electrode, which will help to meet DOE's energy density target.

Reviewer 2:
The reviewer commented that the project is just getting started with good progress so far. The next 6-9 months will be critical in determining overall impact in this reviewer's opinion.

Reviewer 3:
In its initial period of the project, the results and progress are promising and interesting. It is not clear to this reviewer if the team has planned sufficient data collection for this project.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that there are well-defined collaborations that appear to be fruitful.

Reviewer 2:
The reviewer commented that the collaboration is limited only with colleagues in LBNL and possibly ANL. The reviewer suggested the PI look for more experimentalists for collaboration to strengthen the data collection effort to aid model simulation.

Reviewer 3:
The reviewer noted that the work would benefit from mechanical property measurements on the Li anode.

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.

Reviewer 1:
Considering the SEI layer in the model seems to be necessary and challenging, in this reviewer's opinion.

Reviewer 2:
The focus for the future work is well thought, but the plan for execution is not clear to this reviewer. This is particularly problematic with SEI and the application of a mechanical stress field. How the team will accomplish these tasks to collect meaningful data is a bit unclear to this reviewer.

Reviewer 3:
The team presented a lot of options for future work, but the reviewer would like to see further definition and clarification. Ideally, the reviewer hopes the team will focus on 1-2 potential problems and solve them rather than making many shallow contributions to lots of different problems.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said that li-metal deposition and dendrite growth problems are critical for the design and fabrication of high-energy rechargeable Li batteries. With proper model simulation, this project has a good

opportunity to develop a useful knowledge based guidance for the development of the next generation of rechargeable Li batteries. The reviewer pointed out that it may impact the DOE objectives in a noticeable way.

Reviewer 2:

The reviewer noted that this project is significantly related to petroleum displacement, as it will enable higher energy density batteries.

Reviewer 3:

In this reviewer's opinion, enabling Li-metal anodes would be a game-changer for electrochemical energy storage, from both energy density and cost perspectives.

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

Reviewer 1:

The reviewer stated that resources are appropriate.

Reviewer 2:

The reviewer said that the support for the current work seems adequate. However, the reviewer suggested planning more experimental work to collect relevant data for the model and simulation work. This will require more funding support or the team would need to leverage existing projects to collaborate.

Presentation Number: es310
Presentation Title: Advancing Solid-State Interfaces in Lithium-Ion Batteries
Principal Investigator: Nenad Markovic (Argonne National Laboratory)

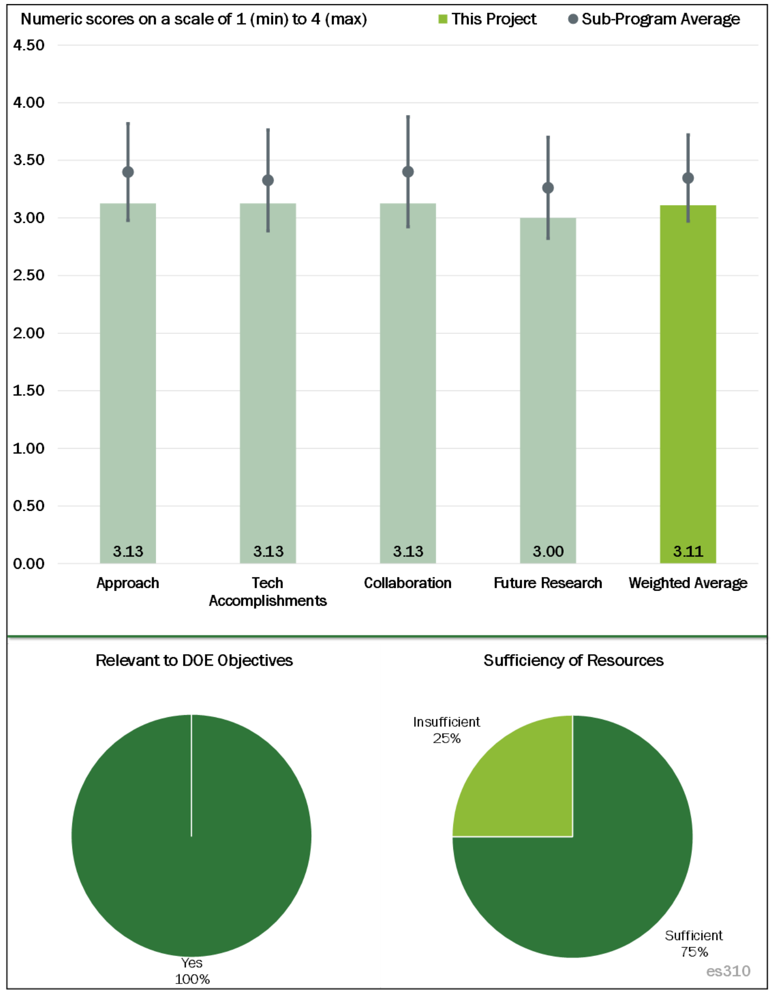

Figure 3-66 - Presentation Number: es310 Presentation Title: Advancing Solid-State Interfaces in Lithium-Ion Batteries Principal Investigator: Nenad Markovic (Argonne National Laboratory)

Presenter

Nenad Markovic, Argonne National Laboratory

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer pointed out that the electrochemical interface between the electrolyte and electrode materials controls the battery performance, and is a main limiting factor for solid state batteries. The interface of the electrochemical system is also the most difficult to study. The approach to investigate this interface using both controlled experiments and modeling is excellent.

Reviewer 2:

The team provided clear descriptions on the synthesis routes and characterization tools to understand how the interface affect the bulk ion transport; however, the team did not address risks and risk mitigations. This reviewer recommended that the team provide some quantifiable milestones based on the interface modeling.

Reviewer 3:

The overall objectives are admirable—to advance our fundamental understanding of electrochemical interfaces. This reviewer's concern is that the experiments are too far afield from relevant systems. This reviewer has no objection to working with model systems, but the model systems should be chosen with more emphasis on relevance to practical systems. For example, the relevance of strontium titanate ($SrTiO_3$) substrates is unclear. Also, the reviewer suggested that LiPON should be seriously considered as a model solid electrolyte system as it is the only "known good" material.

Reviewer 4:

This reviewer is concerned that the materials being used here, such as the surface treatments and electrolytes and the nano-Li islands, bear little or no resemblance to the actual interfaces in Li batteries. The PI stated that one needs "well defined interfaces" to understand what is going on. The issue is that the Li interface appears to be very messy, and that is what we have to learn to deal with.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The results shown to date are generally positive. The project is new, but the reviewer found some of the results interesting. This is a long-term project and it is important that the resources stay allocated for this to achieve its intended impact.

Reviewer 2:
The reviewer noted that the work is only a few months into the three-year long project, and 15% accomplished so far. The reported activities are focusing on leveraging existing capabilities and experimental system set-up. The preliminary results from studying the Li/STO system are interesting and encouraging to this reviewer, and provide validation to the proposed approach.

Reviewer 3:
Results are minimal at this point, although the reviewer notes that the project has only just started.

Reviewer 4:
The reviewer detailed that the project was kicked off in November 2016 and the team's limited results showed that Al-doped LLZO seemed to be kinetically stable with Li-metal based on XAS.

It was not clear to this reviewer how their results on Li/STO surface interaction can be applied to practical Li-ion or future solid state cells. The team did not demonstrate their knowledge on semiconductor optical amplifier (SOA) understanding of the interfacial mechanisms that affect bulk ion transport. The reviewer recommended that the team include Li/LiPON and LiPON/cathode as part of the model interfaces to be studied because LiPON-based solid state cell is the only rechargeable solid state cell that has been commercialized. Insights gained from the study of the LiPON system using their SOA surface characterization will be very useful to the development of new solid state cells in this reviewer's opinion. In addition to the surface chemistry characterization, the reviewer also recommended that the team characterize bulk properties such as lattice mismatch and how that mismatch affects ion transport through at the interface.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that the collaboration within ANL is excellent, and that the external collaborators are well thought-out and carefully chosen.

Reviewer 2:
The reviewer commented that there are well-defined and fruitful collaborations.

Reviewer 3:
According to the reviewer, the team has sufficient equipment and facility for this effort, but the roles of their collaborators were not specified.

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.

Reviewer 1:
The reviewer noted that the research plan for future work is well developed and covers both material development and diagnostic methods developments. The plan effort leverages the exiting capabilities and also develops unique capabilities for this work.

Reviewer 2:
The future work proposed is reasonable. The reviewer encouraged the PI to collaborate with Nancy Dudney at ORNL, who has many years of experience depositing Li films and solid electrolyte films for thin film batteries. Many of these techniques might be useful here.

Reviewer 3:
The reviewer recommended the team devote more effort to understand the electrolyte/cathode interfacial resistance issue. Specifically, ion transport from polycrystalline solid state electrolyte to polycrystalline cathode.

Reviewer 4:
The reviewer reiterated the concern about the choice of model systems. The careful selection of industrially-relevant model systems is critical. Furthermore, selective introduction of controlled defects will be essential to achieve the intended outcomes. These should be defined with considered input from industry.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The electrochemical interface is the critical aspect for solid state battery in this reviewer's opinion. A solid state battery has the promise of better safety, higher energy density, and will be the future battery for EV.

Reviewer 2:
The reviewer commented that this project, if successful, will enable a fundamental understanding of interfaces in solid-electrolyte systems that can revolutionize the safety of electrochemical energy storage devices.

Reviewer 3:
This reviewer noted that it is important to understand how the interface affect bulk ion transport in solid state and hybrid solid state cells.

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

Reviewer 1:
The funding level is sufficient for the work in this reviewer's opinion.

Reviewer 2:
The reviewer stated that $1.5 million/year for 3 years should be sufficient for this effort.

Reviewer 3:
The reviewer commented that the resourcing for this project seems too low relative to the stated objectives.

Presentation Number: es311
Presentation Title: Understanding and Mitigating Interfacial Reactivity between Electrode and Electrolyte
Principal Investigator: Larry Curtiss (Argonne National Laboratory)

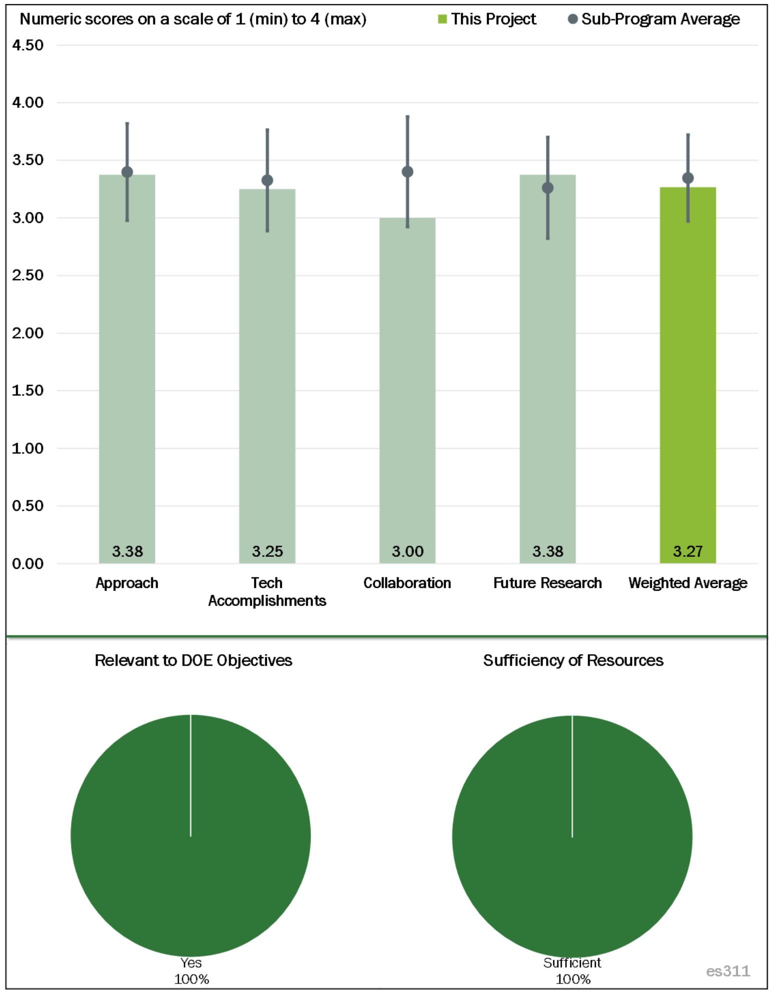

Figure 3-67 - Presentation Number: es311 Presentation Title: Understanding and Mitigating Interfacial Reactivity between Electrode and Electrolyte Principal Investigator: Larry Curtiss (Argonne National Laboratory)

Presenter
Larry Curtiss, Argonne National Laboratory

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that understanding and mitigating the interfacial side reactions between the electrolyte and electrolyte are important to achieve longer life/high voltage rechargeable batteries. Combining experiments and modeling is a very effective approach to tackle this problem, opined this reviewer. Additionally, the choices of system and testing methodologies are very relevant to the problems. The reviewer further noted that experiments and modeling are well designed to understand the mechanisms.

Reviewer 2:
This reviewer commented that the approach is well considered. The experimental capability that this project aims to develop can provide critical insights and fundamental measurements that can directly and immediately impact the design of high-energy, long-life batteries.

Reviewer 3:
The reviewer noted a good strategy to start with characterizing the lithium cobalt oxide ($LiCoO_2$)/electrolyte then applying the insight to the nickelate/electrolyte system. The project team also provided details on how it plans to use high-precision cycler, gas chromatography/DEMS, surface characterization tools, and modeling to understand the electrolyte/cathode interface. Although the milestones were clearly specified, this reviewer observed that the project team did not provide risks or risk mitigations.

Reviewer 4:
This reviewer observed a good approach to use first principal’s modeling and surface characterization techniques to try and understand the NMC/electrolyte interface. Although the focus on Al corrosion is a good

way to prove out the techniques, the reviewer was not convinced that Al corrosion is a first order problem with high-V Li-ion cells. The reviewer has seen little evidence for this even after many years of study in the 1990s at LBNL, and through multiple interactions with Li-ion cell developers.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

Although a new start and only 15% into the project, this reviewer commented that the project team has already generated results on the understanding of interface reactivities in the electrochemical system, particularly for the Al current collector (cc) corrosions. The milestones have been clearly spelled out and progress has been well documented. The reviewer observed a lot of effort on technique, protocol, and instrumentation development in the first half year to pave the way for future investigation.

Reviewer 2:

The reviewer noted very good accomplishments, especially the construction of a micro-amp measurement device for the detection of leakage currents due to side reactions. It was encouraging that the team developed a method to detect Co dissolution from an LCO cathode. When this is applied to NMC, the reviewer expressed interest in the detected current as it relates to Mn dissolution, Ni dissolution, and Co dissolution.

Reviewer 3:

This reviewer asserted that the project team already achieved good understanding on the corrosion of the Al current collector via the use of high precision cycler, and developed a good mechanism on the aluminum fluoride (AlF_3) passivation layer on Al cc, even though the project was only 15% complete. The project team demonstrated good understanding of the various corrosion mechanisms on Al cc, and its *in situ* dissolution study of LCO provided an understanding of the instability of LCO greater than 4.6V. The reviewer indicated that the project team needs to couple its surface characterization with electrochemical characterization to understand the decomposition mechanism as a function of charge cut-offs, which would enhance understanding of the electrolyte/cathode interfacial issue at high voltages.

Reviewer 4:

The reviewer offered the following observations: the experiments to date are interesting to demonstrate the capability, but the impact is unclear; the reviewer added that studying Al passivation is interesting, but the significance is not immediately clear; and the mechanistic understanding is admirable, but one additional step is needed to connect this to practical implications. Moving forward, this reviewer advised that it will be critical to probe relevant model systems. Of particular importance would be to understand the catalytic changes that occur when moving from moderate Ni (50-60 mol%) to high Ni (greater than 70 mol%) materials. Clear, simple conclusions with statements of practical importance are achievable with the unique experimental capability this team has developed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

This reviewer described collaboration within the ANL team as excellent, and noted that each team member contributes uniquely to this project.

Reviewer 2:

Good collaboration was observed by this reviewer, who added that the roles of each collaborator were specified.

Reviewer 3:
The reviewer noted evidence of collaboration, but the degree of coordination could be increased to enhance the impact of the work.

Reviewer 4:
The reviewer expressed surprised that this PI from ANL does not list any of the following as collaborators: the ANL-led high-capacity high-voltage cathode work group; Daikin, who is developing high-V electrolytes for use with high-Ni NMCs; or other developers of high-V cells. As indicated by this reviewer, the ANL HEHV team's mission is to understand and improve high-Ni NMC cathodes operated at high-voltage. Perhaps this collaboration will emerge when the PI moves onto NMC cathodes. The reviewer noted that most of the current work has been on LCO to establish the project's techniques.

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.

Reviewer 1:
The stated future work is clear and the potential impact is enormous from this reviewer's perspective.

Reviewer 2:
The reviewer commented that it is good the project team is moving on to NMC.

Reviewer 3:
This reviewer asserted that milestones for the remaining of the year are well thought and a logical continuation of earlier milestones. The next year's planned activities are very relevant to this year's work. The reviewer added that planned activities on the cathode materials address the need for critical high-voltage materials. This reviewer suggested including appropriate decision points in the planned activities.

Reviewer 4:
The reviewer noted that the proposed effort to further study the coated nickelate/electrolyte interface and understand the effect of voltage on metal dissolution and other decomposition products is greatly needed. This reviewer recommended that the project team also characterize the coated Al cc as part of the cathode/electrolyte study.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
This reviewer asserted that stability of high-Ni NMC/electrolyte interfaces at high voltage is a critical issue for LIBs.

Reviewer 2:
The reviewer commented that understanding and mitigating interface side reactions may lead to long life time and high energy density rechargeable batteries.

Reviewer 3:
This reviewer noted that this work can provide clear results to enable long-life high-energy batteries.

Reviewer 4:
The reviewer indicated that understanding the electrolyte/cathode interface is key to improving stability of the high-voltage Li-ion systems. To make it more relevant, this reviewer suggested that the project team apply its

Al corrosion study to the coated Al cc and study AlF_3 passivation layer stability as a function of the charge cut-off voltage.

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

Reviewer 1:
The reviewer commented that resources are sufficient for the planned work.

Reviewer 2:
This reviewer indicated that $800,000/3 years is sufficient for this effort.

Reviewer 3:
The resources appear to be adequate from this reviewer's perspective.

Presentation Number: es312
Presentation Title: Daikin Advanced Lithium-Ion Battery Technology—High-Voltage Electrolyte
Principal Investigator: Joe Sunstrom (Daikin America)

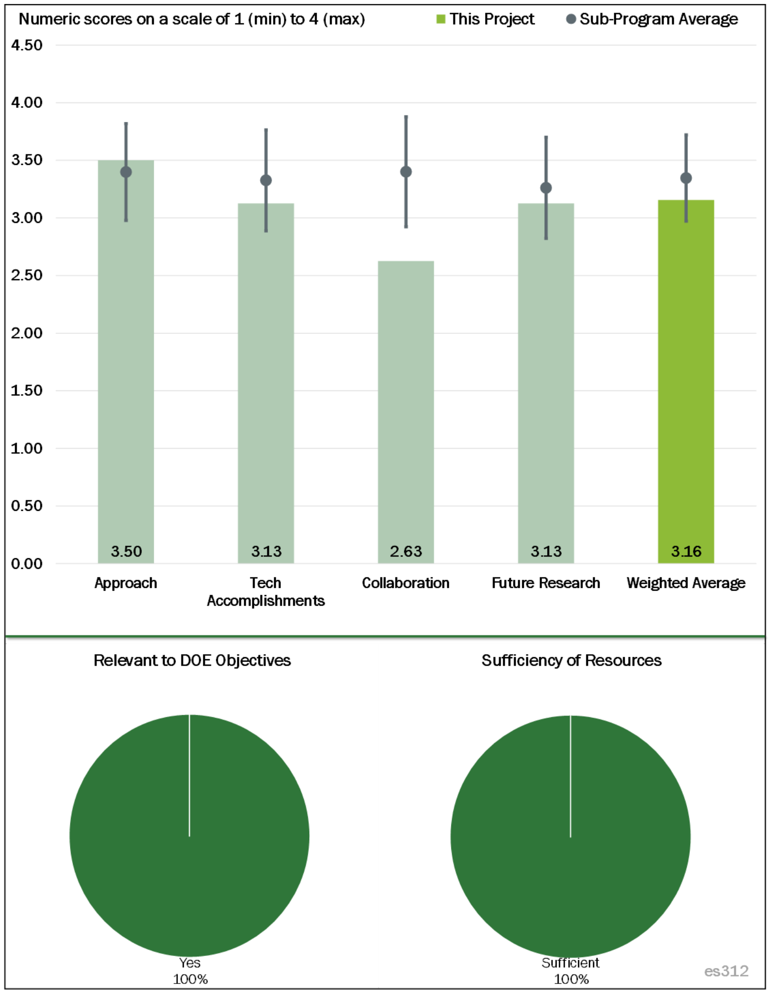

Figure 3-68 - Presentation Number: es312 Presentation Title: Daikin Advanced Lithium-Ion Battery Technology—High-Voltage Electrolyte Principal Investigator: Joe Sunstrom (Daikin America)

Presenter

Joe Sunstrom, Daikin America

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

This reviewer commented that fluorinated carbonates solvents and additives have been known to stabilize high-voltage cells, and that systematic investigation of this class of materials is very beneficial to improve performance of high-voltage LIBs. Additionally, the reviewer noted that Daikin America Inc. is uniquely suitable to perform this investigation, as it both a fluorinated compounds manufacturer and an electrolyte company.

Reviewer 2:

The reviewer liked the approach of trying to understand the role of fluorinated additives on the stability of electrolytes at high V, as well as the use of three go/no go decision points. Using this approach in other BMR projects was also encouraged by this reviewer. The reviewer liked the goal of 5V stable electrolyte that is self-extinguishing, and suggested putting more weight on the 5V stability.

Reviewer 3:

The reviewer noted that this is a good systematic study of the voltage cut-off impact on the stability of electrolyte with fluorinated additive. The combination of electrochemical and analytical characterizations should provide good understanding of the failure mechanism in high-voltage electrolyte and enable optimization of electrolytes for high-voltage cells. This reviewer observed a lack of quantified milestones and that technical risks and risk mitigations were not discussed.

Reviewer 4:

This reviewer indicated that development of electrolytes that are stable to high-voltage is an important area with clear impact. The reviewer advised that greater attention should be paid to ensuring the compatibility of these solutions with practical (e.g., graphite) anodes, or the utility will be diminished.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
This reviewer observed good accomplishments to date tying together gassing and likely internal cell reactions.

Reviewer 2:
The reviewer reported that this project is a new start and only a half-year into a three-year project. The work so far has been mainly in establishing baseline performance of classic electrolyte and FEC additives in high-voltage cells, which is a correct initial step for new electrolytes and additives development. This reviewer opined that progress is normal and the overall work supports DOE goals.

Reviewer 3:
The reviewer indicated that although the project is a new start and 17% complete, the project team has already made significant progress on characterizing the stability of electrolytes as a function of gas generation at increasing charge cut-off voltages. Gas generation results confirmed current understanding that the cathode/electrolyte interaction dominated the instability issue of high-voltage cells. This reviewer added that the project team needs to demonstrate understanding of the electrolyte/high-voltage cathode stability issues and provide a rationale for how its fluorinated additives will enable stability above 4.6V

Reviewer 4:
This reviewer commented that the work is addressing high-voltage stability at the cathode/electrolyte interface. However, the results to date show poor anode/electrolyte interface stability and no clear work plan was presented to improve this critical characteristic.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer indicated that it is appropriate this project is entirely within Daikin.

Reviewer 2:
Although it is not explicitly mentioned in the presentation file, this reviewer noted that Daikin American has collaborations with both national laboratories and industry.

Reviewer 3:
This reviewer encouraged the team to reach out to the ANL HEHV cathode team.

Reviewer 4:
The reviewer observed that the project team had not identified collaboration partners. Additionally, it was unclear where the project team will perform some of the surface characterizations, such as ToF-secondary ion mass spectrometry, and XPS.

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.

Reviewer 1:
The reviewer asserted that stability of the anode/electrolyte interface must be improved for these electrolytes to have practical applications.

Reviewer 2:
In addition to the proposed effort, this reviewer noted that the project team may want to devote some effort to understand whether the fluorocarbon performance decrease between 4.5V and 4.6V is due to the cathode or electrolyte.

Reviewer 3:
The reviewer commented that the proposed detailed study of gas composition and kinetics as a function of voltage and detailed study of electrolyte film are very important areas to investigate electrolyte failure at high-voltage. However, the project team needs to establish a strong connection between these studies and the overall objective of developing high-voltage solvent systems and additive packages.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer asserted that the project is highly relevant to both DOE and industry objectives.

Reviewer 2:
This reviewer explained that high-voltage stable electrolyte is a critical component for enabling a high-energy battery. The reviewer further commented that this project is aimed at understanding the failure mechanism of baseline electrolyte at high-voltage, and developing high-voltage stable electrolyte solvent systems and additive packages.

Reviewer 3:
The reviewer indicated that nearly all roadmaps for advanced batteries call for high-voltage systems; this is a critical area of development.

Reviewer 4:
This reviewer commented that this is a very relevant study needed to understand and stabilize the electrolyte for high-voltage Li-ion cells.

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

Reviewer 1:
The reviewer noted that resources are appropriate.

Reviewer 2:
This reviewer commented that $1.8 million over 3 years should be sufficient for this effort.

Reviewer 3:
The reviewer opined that the cost share by Daikin is good, 30%. Cost is relatively high compared to other projects at this level of commercial maturity.

Reviewer 4:
Sufficient resources were observed by the reviewer for this project to achieve the milestones. This reviewer added that lab expansion is needed to be able to evaluate the different electrolyte samples.

Presentation Number: es313
Presentation Title: Performance Effects of Electrode Processing for High-Energy Lithium-Ion Batteries
Principal Investigator: David Wood (Oak Ridge National Laboratory)

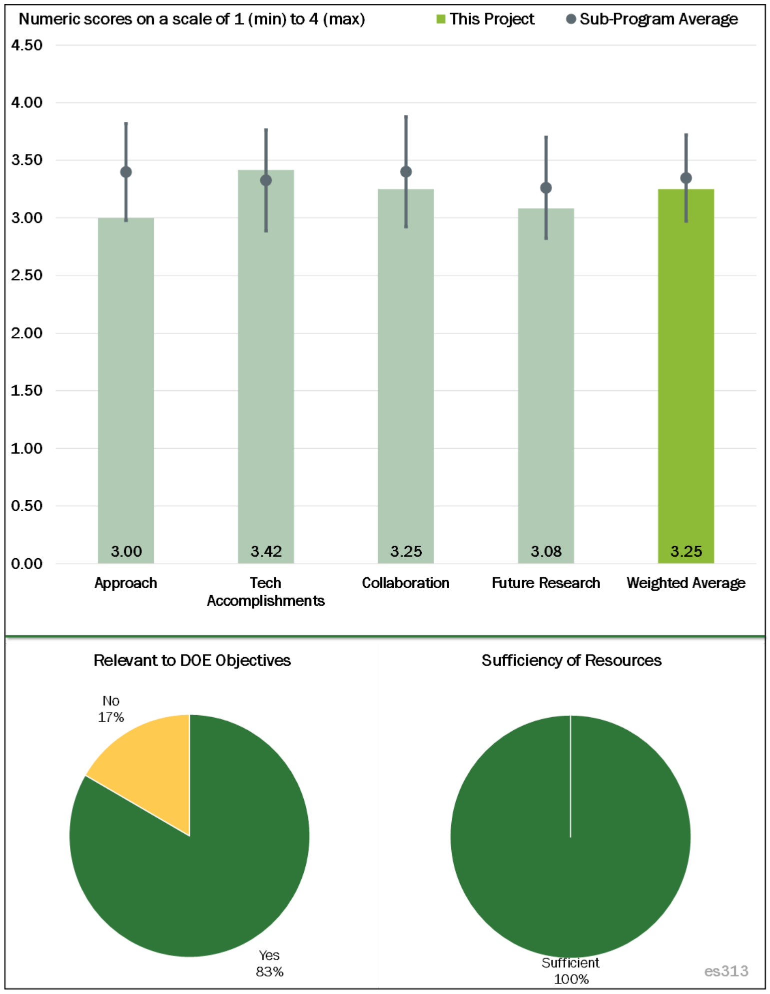

Figure 3-69 - Presentation Number: es313 Presentation Title: Performance Effects of Electrode Processing for High-Energy Lithium-Ion Batteries Principal Investigator: David Wood (Oak Ridge National Laboratory)

Presenter

David Wood, Oak Ridge National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

This reviewer described the approach as well-outlined. If successful, the effort will result in a better understanding of the process-property-performance relationships for Li-ion electrodes. The reviewer asserted that this type of strategy is necessary to meet low-cost, high-performance battery goals.

Reviewer 2:

The reviewer commented that this project aims to develop an aqueous-based electrode processing procedure for high-energy NMC and NCA cathode materials. The reviewer noted that the project appears to be well-designed, difficult but feasible, and aligned with other DOE efforts.

Reviewer 3:

This reviewer indicated that the project is highly relevant for reducing the cost of manufacturing cells with high specific energy.

Reviewer 4:

The reviewer reported that the approach is to reduce cost by developing aqueous-based process for nickelate electrodes and improve energy density by making thick electrodes. This reviewer also observed quantifiable milestones based on measuring the cathode stability and subsequent cell performance as a function of exposure time to water. The reviewer added that nickelate materials are irreversibly degraded by moisture; unless this barrier is addressed first, it makes no sense to develop an aqueous-process for the nickelates electrode.

Reviewer 5:

The reviewer observed that this project has substantial overlap with the much larger (in terms of funding) project, ES164 (i.e., Thick Low-Cost, High Power Lithium-Ion Electrodes via Aqueous Processing). Given the overlap in technical foci, lead laboratory (ORNL), partners, and staff, the reviewer commented that it is a poor approach to treat this as a separate project. This reviewer further noted that most of the results of this project are integral to the success of ES164. The reviewer explained that the approach is acceptable if the two projects are fully integrated at the performance level and the separation into two distinct designations is simply an artifact of funding. This project certainly addresses issues that must be resolved to produce reliable, consistent, high-performing cells in large quantities. This reviewer also noted it is good the project recognizes that processing characteristics of some of the newer materials (e.g., Ni-rich cathode materials) may be different from current, common materials.

Reviewer 6:

Although several different research areas were highlighted, this reviewer commented that the "sharp focus" of the program was a little bit unclear. The reviewer explained that "manufacturing improvements" is a very broad category; there may be some benefit to detailing the focus, timeline, and objectives. This reviewer also indicated that tracking progress on so many different activities towards a general DOE goal is hard.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

Given that this project had only been active for a few months before the poster paper was prepared, this reviewer commented that the results reported are reasonable and appropriate. The reviewer explained that new battery materials will be required to meet DOE's goals; some of these new materials may require modifications in the way that they are processed relative to current practice. This reviewer asserted that the project is designed to identify any required modifications. The reviewer noted that some sections of this project (e.g., investigating cell formation processes) focus on reducing the time and cost of aspects of cell manufacture, which clearly supports DOE's goals for lower cost batteries.

Reviewer 2:

This reviewer indicated that the work done is systematic and directly addresses project goals. Coating from aqueous slurries, chemical and mechanical stability of the electrodes and SEI, and the effect of formation protocols on cycling performance are all very relevant to developing efficient and effective processes for manufacturing.

Reviewer 3:

The reviewer noted that this project just started this fiscal year and has made considerable progress thus far. This reviewer explained that it is well known that the graphite surface plays an important role in electrolyte wettability, reduction potential, and SEI formation. The project demonstrated that UV light can control oxygen levels on graphite resulting in improved cycle life. Additionally, the reviewer reported development of a new method to form cells that can dramatically reduce time.

Reviewer 4:

This reviewer acknowledged that it is early in the project timeline (i.e., only six months of work) and the project is progressing well with the NMC532 cathodes. There is still substantial work to be done with powder stabilization in water, leaching minimization, and improving electrochemical rate performance, but the reviewer opined that the project team has a good start. The reviewer asserted that more electrochemical analysis of aqueous-produced cathode electrodes is required to determine progress towards goals, and that approach feedback from a major cell manufacturer would lead to increased credibility and validity of the project team's approach. This reviewer also commented that it is unclear when or how the project team plans to determine the cost benefits of its approach.

Reviewer 5:

This reviewer reported the following: the project team's study provided valuable data on the stability of different NMC materials as a function of exposure time to water; a shortened formation protocol was developed; and a correlation between rate capability versus electrode loading as a function of porosity was established. Based on understanding of the instability of water-exposed NMC materials, the reviewer recommended that the project team propose a mitigation to reduce the impact of water on aqueous-processed NMC electrodes.

Reviewer 6:

The reviewer commented that there may be some information that can strengthen US supply chain processing knowledge, but this was not demonstrated in some of the examples. For instance, continued this reviewer, shortening the formation process from 5 C/20 cycles is unlikely going to help battery manufacturers. As the presenter remarked, this is because formation protocols likely are shortened and more specific than this pattern already. While it may be good knowledge for ORNL to improve their testing throughput, this reviewer doubted that it will be informative for cell manufacturers today. The reviewer further indicated that specific thickness/porosity tradeoffs are likely part of a cell manufacturer's optimization design of experiments already, and may not be very applicable in broad strokes.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer remarked that strong collaborations exist with many institutions.

Reviewer 2:

It appeared to this reviewer that ORNL is working well with many external partners.

Reviewer 3:

This reviewer observed good collaboration with various team members, and that the role of each member was clearly specified.

Reviewer 4:

The reviewer commented that the project lists adequate collaborations, but did not indicate whether ORNL or a partner will develop cost-benefit analysis of aqueous processing.

Reviewer 5:

This reviewer reported that collaborative partners are identified and specific tasks for several of them are clearly stated. The reviewer noted the following collaboration weaknesses: lack of a battery manufacturer who has a significant business base in cells for use in passenger vehicles; and the lack of stated coordination with ES164.

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.

Reviewer 1:

This reviewer reported that proposed future work is focused on areas highly relevant to achieving DOE goals. These include lowering the formation and wetting time of the cell to less than 24 hours and investigating different Si anode manufacturing methods.

Reviewer 2:

The reviewer described future work as reasonable.

Reviewer 3:
Future work to this reviewer seemed logical, but lacks appropriate decision points and clear alternative development pathways for risk mitigation. High energy cathodes with protective coatings should be considered as alternative materials pending continual leaching problems. The reviewer advised a focus on substantial electrode processing characterization and cost analysis.

Reviewer 4:
This reviewer recommended that the shortened protocol should be further validated for SEI stability by measuring the self-discharge rate. The reviewer further observed a need to quantify the performance of dried water-exposed NMC cathodes in cells.

Reviewer 5:
The reviewer expressed difficulty with judging proposed future work. This reviewer noted a wide range of topics being studied, and there did not seem to be clear gates or planned milestones.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer remarked that this effort is very relevant to overall DOE objectives. The development of high-performance, low-cost electrodes for LIBs is at the core of the petroleum displacement objective.

Reviewer 2:
This reviewer commented that decreased processing costs can translate to decreased cell costs, increased EV adoption, and, therefore, potential petroleum displacement.

Reviewer 3:
The reviewer explained that new battery materials and new manufacturing processes will be necessary to meet DOE goals for battery cost, energy density, and specific energy. This reviewer opined that the questions addressed by this project are all relevant to understanding these new materials and processes. This understanding is necessary before the materials and processes can be used in a manufacturing environment.

Reviewer 4:
This reviewer asserted that low-cost manufacturing processes for batteries will help increase the adoption of electric vehicles.

Reviewer 5:
The reviewer commented that it is well known that nickelates are irreversibly degraded by moisture. Thus, it was not clear to this reviewer why there is a need to investigate aqueous-based process for the nickelates electrodes, even if there might be cost benefit.

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

Reviewer 1:
The reviewer noted sufficient resources to achieve stated milestones in a timely fashion.

Reviewer 2:
This reviewer commented that the resources are sufficient in order to successfully complete the effort in a timely manner.

Reviewer 3:
The reviewer remarked that $1 million should be sufficient for the three-year effort.

Reviewer 4:

This reviewer indicated that the facilities and staff of the lead laboratory and its partners are clearly adequate to accomplish the goals of this project. Although no detailed financial data are provided, the reviewer described the total funding as reasonable.

Presentation Number: es315
Presentation Title: Developing Flame Spray Production Level Process for Active Materials
Principal Investigator: Greg Krumdick (Argonne National Laboratory)

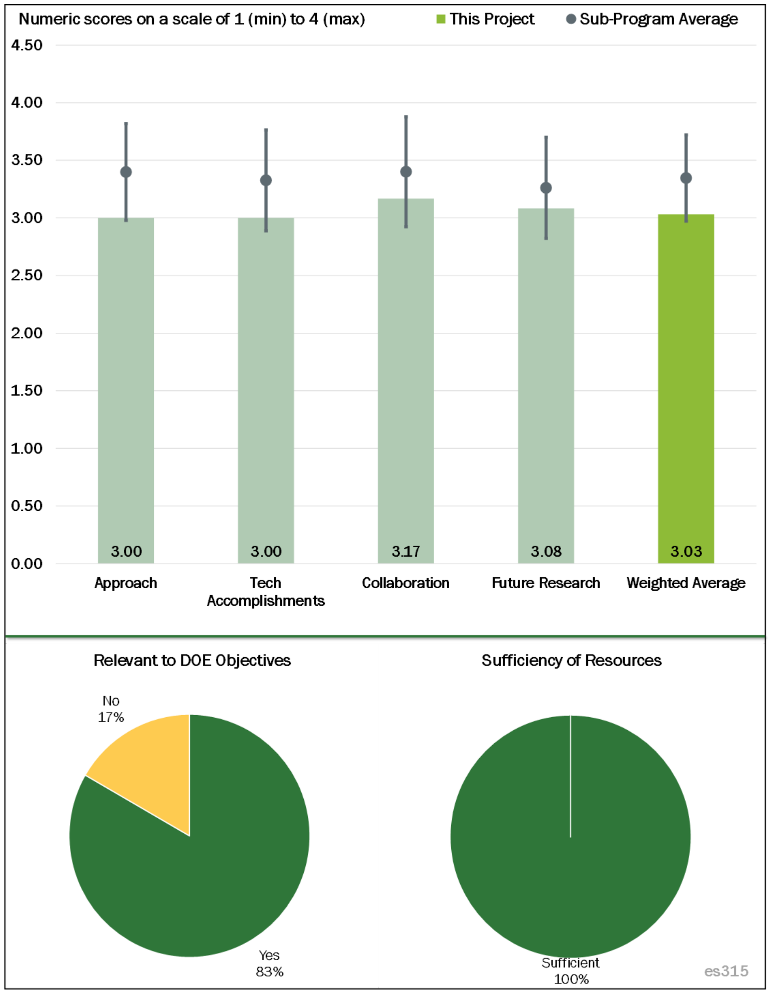

Figure 3-70 - Presentation Number: es315 Presentation Title: Developing Flame Spray Production Level Process for Active Materials Principal Investigator: Greg Krumdick (Argonne National Laboratory)

Presenter

Greg Krumdick, Argonne National Laboratory

Reviewer Sample Size

A total of six reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

This reviewer viewed the approach as relevant, and reported that the project team will develop a flame spray pyrolysis synthesis procedure with guidance from an industrial partner to ensure affordable, high-performance materials.

Reviewer 2:

The reviewer observed an excellent approach for establishing the capability to utilize the flame spray pyrolysis method. However, it was unclear to this reviewer how the method will be evaluated in comparison with standard methods.

Reviewer 3:

This reviewer described the approach as interesting, and inquired about the cost by kg.

Reviewer 4:

The reviewer commented that flame spray combustion synthesis is an industrial technology used for the synthesis of carbon nanoparticles and simple oxides. This project aims to use the knowledge of the existing technology and adopt it for the manufacturer of more complex transition-metal oxides that are used as electrode in LIBs. The reviewer noted that one barrier to the adoption of this technology is the small size of particles synthesized by combustion methods. In order to address this issue, the reviewer reported that the project team modified the system by increasing the exposure time to high temperatures. At elevated temperatures, particles usually agglomerate and form larger particles. This reviewer added that the concern here is presence of weak agglomerates with poor attachment of particles, which could result in degradation of battery electrodes.

Reviewer 5:
The reviewer noted a reasonable approach to reduce cost by eliminating the calcination step and combining the cathode and carbon matrix during the flame spray synthesis. It was recommended by this reviewer that the project team provide a cost model and show how the flame spray process can reduce cost versus traditional calcination.

Reviewer 6:
This reviewer expressed interest in more convincing details or evidence that flame spray pyrolysis can deliver the claimed benefits (e.g., reduced cost, better purity, crystallinity, etc.). One of the key needs in active materials is uniformity in particle size, and yet having particles large enough to be easily handled. It was not convincingly demonstrated to this reviewer how this work would do on this metric.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer remarked that good progress was achieved this past year: system engineering was completed; major components were ordered; and several of the major components were installed.

Reviewer 2:
The reviewer reported that the flame spray synthesis system and all the necessary equipment are successfully installed and tested. The preliminary results show that complex cathode compositions can be obtained and the proposed system can simplify the battery manufacturing and is a step toward roll-to-roll battery manufacturing.

Reviewer 3:
Although this review was early in the method development, the reviewer commented that the project seems to be on schedule to begin making materials.

Reviewer 4:
This reviewer highlighted possibly mislabeled fiscal years on Slide 5. If so, it appeared to the reviewer that the project is on track toward a completed device. The device seems well-designed and robust. However, this reviewer preferred to see more validation steps built into the progress steps, and added that it seems as if the device will be turned on at the end of the project at which point the project team will find out if it works or not.

Reviewer 5:
The reviewer acknowledged that the project team set up the equipment, but it was difficult to assess project success. The reviewer commented that there is no analytical data or performance data on the materials produced by the flame spray analysis, and that analytical and performance data should be part of the quantifiable milestones.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer indicated that the project team is collaborating with the leading companies in flame spray technology.

Reviewer 2:
This reviewer opined that the inclusion of Cabot and Praxair is promising for developing a practical application of these methods.

Reviewer 3:
The reviewer noted good collaboration with industrial partners and that the role of each member was specified.

Reviewer 4:
This reviewer observed good collaboration with other institutions, including Cabot, Praxair, and Professor Pratsinis (ETHzurich).

Reviewer 5:
It seemed to this reviewer that there should be more collaboration or regular discussions with Pratnisas, who is the acknowledged expert on this technology. Other than that, the reviewer remarked that inclusion as part of MERF ensures pretty good collaboration with battery researchers once this project is completed.

Reviewer 6:
More collaboration with cathode producers was indicated by this reviewer.

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

Reviewer 1:
This reviewer described future plans, in regards to powder production scale-up and roll-to-roll battery electrodes manufacturing, as well-detailed and aligned with the project goal.

Reviewer 2:
The reviewer indicated that future plans are a logical extension of the past year, and reported that plans are in place to begin developing the NCM procedure with Cabot and Praxair.

Reviewer 3:
The reviewer observed many exciting materials to be made with this device, once it is up and running.

Reviewer 4:
This reviewer commented that very little detail about the future experiments was given, but acknowledged that it is early in the process.

Reviewer 5:
The reviewer reported that the project is 95% complete and suggested a focus on characterizing the materials produced by the flame spray method rather than exploring different aerosol synthesis with the remaining funding.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer commented that this effort is relevant to the overall DOE objectives. The development of affordable, high-performance cathode materials for an EV LIB is at the core of the petroleum displacement objective.

Reviewer 2:
This reviewer indicated that the project will enable low-cost production of high-quality cathode materials with enhanced performance. This will accelerate use of high-energy LIBs in the automotive industry and other sectors.

Reviewer 3:
The reviewer remarked that this work improves U.S. technological ability to improve manufacturing of electrode materials for vehicle electrification.

Reviewer 4:
This reviewer stated that new methods should be evaluated to try to develop superior processes.

Reviewer 5:
It is unclear to this reviewer why ANL, a national laboratory, is investigating methods to reduce cathode synthesis cost. Per the slides, ANL followed the guidance of industrial partners, which led the reviewer to question why an experienced industrial company was not contracted for this task. The reviewer added that this task is better suited for a commercial cathode company.

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

Reviewer 1:
This reviewer remarked that the project team has access to sufficient resources and collaborations in order to perform the proposed tasks.

Reviewer 2:
The reviewer described resources as sufficient to successfully complete the effort in a timely manner.

Reviewer 3:
This reviewer commented that resources appeared adequate.

Reviewer 4:
The reviewer opined that $500,000 is insufficient for this project, and noted that most of the funding was used to set up the flame spray equipment. This reviewer explained that there should be sufficient funding for capital cost and materials characterization for work to be done at a commercial cathode company.

Presentation Number: es331
Presentation Title: Development of a High-Energy Density EV Cell
Principal Investigator: Mohamed Alamgir (LG Chem Power)

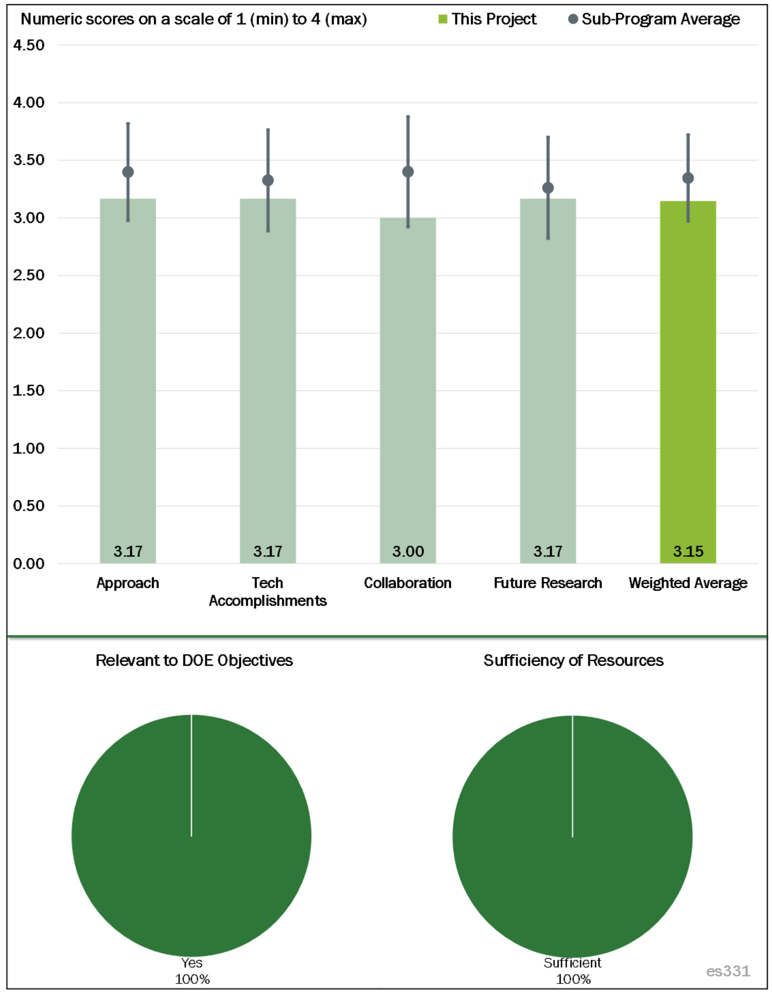

Figure 3-71 - Presentation Number: es331 Presentation Title: Development of a High-Energy Density EV Cell Principal Investigator: Mohamed Alamgir (LG Chem Power)

Presenter
Mohamed Alamgir, LG Chem Power

Reviewer Sample Size
A total of three reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
The objective for this project, as understood by this reviewer, is to develop a high-energy and low-cost Li-ion cell and module that will provide 200-mile range per charge, as desired by the USABC BEV program. The reviewer reported that specific cell-level performance targets are 750 Wh/l and $100/kWh, which require high specific energy (high capacity and/or voltage) cathodes, such as the Mn- and Ni-rich LL composite oxides and high capacity anodes (e.g., Si anodes). The plan is to deliver the cells and modules with these enhanced performance characteristics to DOE laboratories for testing. The reviewer stated that the approach focuses on Mn-rich cathodes and Si-based anodes, as well as improving performance and life by optimizing electrode structures, surface coatings, and electrolyte compositions. Eventually, low-cost modules will be designed with adequate mechanical integrity, fabricated for performance demonstration. Appropriately, the materials tested here are among the most promising options. Overall, this reviewer described the project as well designed and integrated with other efforts.

Reviewer 2:
This reviewer explained that the LG Chem project studies Mn-rich cathode using scaled-up ALD coating, paired with SiO anode, to deliver cells meeting the USABC target specifications (i.e., 750 Wh/l and $100/kWh). The reviewer added that this is a practical and promising approach to goals in the 200-mile USABC BEV program.

Reviewer 3:
The reviewer commented that the original scope and approach of the project is changing, based on discussions with the PI. The original emphasis on LMR-NMC is shifting to a high-Ni NMC. This was quite understandable to the reviewer, considering the challenges of LMR-NMC. This reviewer added that the project team will be giving something up in energy, but should gain in life.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
Without describing a lot of the details, the reviewer remarked that the PI presented data from a number of tests, mostly based on cycle life, and examined various active materials.

Reviewer 2:
This reviewer observed good progress made in evaluating Mn-rich and Ni-rich materials as high-capacity cathodes and various Si-based materials as anodes. Studies were carried out to demonstrate the stability of Mn-rich and Ni-rich cathode materials with ALD coatings. The reviewer explained that these coatings improve the cyclic stability of these cathodes, especially when cycled to high charge voltages, while thicker coatings affect the rate capability. Although trends are clear on the cycle life benefits, this reviewer pointed out that the cycle life data shown here is not stellar, with a high capacity fade (i.e., 10% over 50 cycles). Also, studies were carried out with dense electrodes (i.e., with high loadings of active materials), but the reviewer found that the details are not provided here on this aspect. Likewise, comparative studies were made on various Si-based anode materials (e.g., SiO, Si alloy, and Si-C composites) with different binders, electrode porosities, and electrolytes. Low volume expansion and good cycle life have been reported with the SiO-based anode, though the reviewer highlighted that details also are lacking on the loadings (or mAh/cm^2). The performance in full cells is not that encouraging in terms of cycle life. Based on the data presented, it was difficult for the reviewer to know where the project is in terms of meeting the DOE goals of 750 Wh/l (specific energy not targeted). Similarly, this reviewer advised that proper cost analysis needs to be made showing that the proposed material and cell/module designs will get the project closer to the cost goals. Overall, the reviewer asserted that progress is consistent with the scheduled milestones and DOE goals.

Reviewer 3:
According to the reviewer, the project team demonstrated that ALD coated Mn-rich cathodes have greater than 80% capacity retention for up to 50 cycles. However, the reviewer observed no data from uncoated cathodes for comparison. The project team also demonstrated that more ALD coating will lower rate capability. This reviewer explained that the project team needs to find an optimized amount of coating for maximum electrochemical performance. The project team also compared the cycling performance of Si-alloy- and SiO-based full cells. The reviewer reported that results show SiO is significantly better in terms of cycle-life.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
Only a limited number of collaborations were observed by this reviewer.

Reviewer 2:
Although there are no collaborations on this project for the material or cell/module development for proprietary reasons, this reviewer pointed out that there are on-going collaborations with DOE laboratories to evaluate cells and modules delivered in this project.

Reviewer 3:
This reviewer commented that LG Chem does not show any collaboration with universities and national laboratories. However, the reviewer acknowledged that LG should have enough resources internally, and that the project team also communicates with USABC 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.

Reviewer 1:
This reviewer observed a good path forward, and also pointed out that the project team has a ways to go for a vehicle battery.

Reviewer 2:
The reviewer reported that LG Chem's future work will be concentrated in both materials improvement and cell design optimization.

Reviewer 3:
This reviewer opined that planned future work is logical and consistent with USABC goals. Future studies, as observed by this reviewer, will do the following: continue to improve cell energy density, by improving the materials (i.e., cell components); improve cell design optimization; and, in particular, improve SiO anode durability. Based on the data presented here, the reviewer indicated that the project is still farther away to demonstrate adequate performance (specific energy and durability) from the materials to meet the targets battery goals. Subsequent to this material development, this reviewer also noted large-sized EV cells will be built and delivered to DOE laboratories for evaluation.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer remarked that this project targets the DOE objective of petroleum displacement by developing battery cells for use in the 200-mile USABC BEV program very well.

Reviewer 2:
This reviewer described the project team's work as very relevant.

Reviewer 3:
The reviewer explained that low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles. High capacity cathode and anode materials are required to improve the specific energy of Li-ion cells. Additionally, new, low-cost modules designs are required to bring the battery cost to $100/kWh. This reviewer concluded that successful implementation of this project will thus address the key barriers of low energy densities and high cost for EV batteries.

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

Reviewer 1:
This reviewer described the project team resources as sufficient.

Reviewer 2:
The reviewer opined that resources are adequate based on the project scope ranging from material development and cell fabrication to module development.

Reviewer 3:
LG Chem demonstrated to this reviewer that it can conduct the project with its own technologies.

Presentation Number: es332
Presentation Title: High Electrode Loading EV Cell
Principal Investigator: William Woodford (24M Technologies)

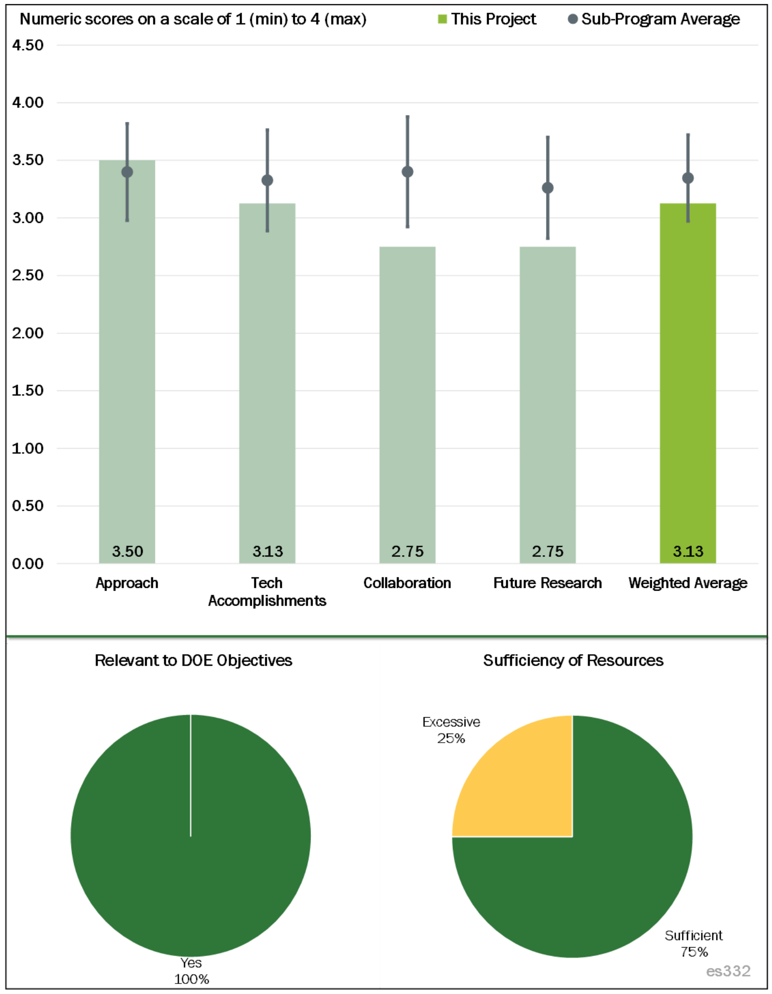

Figure 3-72 - Presentation Number: es332 Presentation Title: High Electrode Loading EV Cell Principal Investigator: William Woodford (24M Technologies)

Presenter
William Woodford, 24M Technologies

Reviewer Sample Size
A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
This reviewer commented that 24M is working on the three most critical barriers for further commercialization of EVs (i.e., cost, performance, and safety).

Reviewer 2:
The reviewer remarked that this is a very novel and exciting approach for making LIB electrodes. Advantages identified by this reviewer include cost, abuse tolerance, and energy density.

Reviewer 3:
Referencing a number of background slides that described the project team's technology, this reviewer described the approach as interesting and unique.

Reviewer 4:
The reviewer recounted that the objective is to develop EV-rated Li-ion cells using proprietary semi-solid electrode technology; specifically, to increase the energy density of semi-solid electrodes through chemistry and cell design improvements (with reduced separators and current collectors), and to demonstrate scalability and abuse tolerance with semi-solid electrode architecture. This architecture will address two critical barriers for current Li-ion cells: inactive material fraction is too high; and the project team's percentage of cost is too high. The reviewer noted that these flowable high-energy density Li-ion electrodes allow for low-cost manufacturing and provide high area-specific capacity (mAh/cm^2), specific energy, and energy density. Enabling proper use of the active material in these dense electrodes, the porosity/tortuosity needs to be sufficiently high, as is being done here using magnetic methods. With fewer unit operations for the electrode fabrication and low capital equipment costs compared to the conventional Li-ion cells, the reviewer indicated that this modified design is expected ease scale up and be amenable for high volume manufacturing. It was unclear to the reviewer how this semi-solid electrode design will provide improved abuse tolerance. Overall, this reviewer opined that the approach addresses two main technical barriers of Li-ion cells; also, the project is well designed and integrated with other efforts.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This reviewer reported that the energy density goal has been met, on schedule, but also observed there is a long way to go to prove viability, including low-temperature performance because of thick electrodes.

Reviewer 2:

The reviewer explained that 24M's flowable Li-ion cathode and simpler device architecture enable improved energy density at lower cost. Additionally, the 24M cell design has unique abuse tolerance. The reviewer did highlight some delays in the anode active materials downselection.

Reviewer 3:

This reviewer commented that good progress has been made with the high-capacity cathode materials in this architecture. High areal capacities (10 mAh/cm^2) have been demonstrated in several Ni-rich cathodes in pouch cells. The reviewer reported that the versatility of the semi-solid electrode platform is being demonstrated with the NCM111/Graphite couple. Additionally, high power-to-energy performance has been claimed in semi-solid cells with high areal capacity electrodes. The reviewer also noted that both cell chemistry and architecture improvements are being improved to further increase energy density toward the EV 2020 targets. Assuming it would not be proprietary, and to appreciate the capabilities of this architecture, it would have been helpful to the reviewer if some rate data was presented on the cells containing these dense electrodes. The anticipated Phase-1 goals in the Gap Analyses have been met in most of categories, except low-temperature performance, as may be expected. The reviewer also suggested it would be useful to know which of the dense electrodes (i.e., NMC11 or graphite) is rate-limiting at low temperatures. Also, it appeared to this reviewer that the anode development appears to be lagging behind for want of personnel. The round-trip energy efficiency of 90% reported in the early work is lower than normal (95%), implying higher electrode polarization. Further, the reviewer found that no information is provided on the specific energy and energy density of cells, or on the cost benefits associated with this design. Generally, the reviewer observed little performance data to make a proper assessment of this architecture. Overall, this reviewer remarked that the technical accomplishments are notable; progress is good and consistent with DOE goals.

Reviewer 4:

This reviewer had many questions about the stability and performance of the project team's thick "clay-like" electrodes, and pointed out that there are only limited results presented, generally. The reviewer highlighted that the project team even redacted the discharge capacity of its cathodes, using standard electrode materials, which made the reviewer wonder what the project team is trying to hide.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

This reviewer remarked that an Advanced Research Projects Agency—Energy program gives the project team a good set of collaborators.

Reviewer 2:

The reviewer commented that 24M did not list any collaborators from other universities and national laboratories. However, it is understood that the company has close links to the MIT battery group led by Professor Chiang. This reviewer also noted collaboration with ANL on cell testing.

Reviewer 3:

The reviewer observed no external partners mentioned, but acknowledged that there will be collaborations with the DOE laboratories to have the cells tested for an independent assessment

Reviewer 4:
No real collaboration was apparent to this reviewer.

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

Reviewer 1:
The reviewer noted that 24M a detailed plan for future work, including phase 2 and 3 deliverables (i.e., downselect coating process, final lock electrolyte, and cost optimization).

Reviewer 2:
As relayed by this reviewer, proposed future studies include the following: continue Phase 1 development and deliver Phase 1 deliverable cells for testing at ANL by June 15, 2017 (30x cell); and execute on high-energy density initiatives to achieve Phase 2 and Phase 3 targets. However, the reviewer advised that it would be helpful if there are numbers associated with the demonstration of enhanced performance or reduced cost, which are the technical barriers for the DOE VTO program.

Reviewer 3:
This reviewer observed little detail in the project team's future work.

Reviewer 4:
Although the challenges are clear, the reviewer was unsure how the project team plans to meet them.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
This reviewer noted extremely high relevance, if successful.

Reviewer 2:
The reviewer described this project as very well designed and conducted to support DOE objectives of reaching the EV 2020 targets.

Reviewer 3:
This reviewer asserted that the project team's work is relevant.

Reviewer 4:
The reviewer explained that low specific energies and high costs of LIBs are serious impediments to their widespread adoption in vehicles. Additionally, fabrication of conventional Li-ion cells involves complex, wet/dry/wet operations with an expensive infrastructure and a high proposition of inactive materials resulting in lower specific energy/energy density and higher costs. This reviewer further commented that new methods of electrode fabrication are desired that would lead to improved energy densities, reduced cost, and increased ease of scale up, which are being addressed by the project.

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

Reviewer 1:
The reviewer pointed out that 24M has demonstrated records in achieving its goals in novel battery development.

Reviewer 2:
The project team's resources seemed to be sufficient from this reviewer's perspective.

Reviewer 3:
This reviewer described project resources as okay.

Reviewer 4:
The reviewer remarked that project resources seemed to be excessive because little information is being disseminated for DOE's benefit, and the project is essentially a continuation of the project team's previous DOE project.

Presentation Number: es333
Presentation Title: Silicon Electrolyte Interface Stabilization Focus Group
Principal Investigator: Anthony Burrell (National Renewable Energy Laboratory)

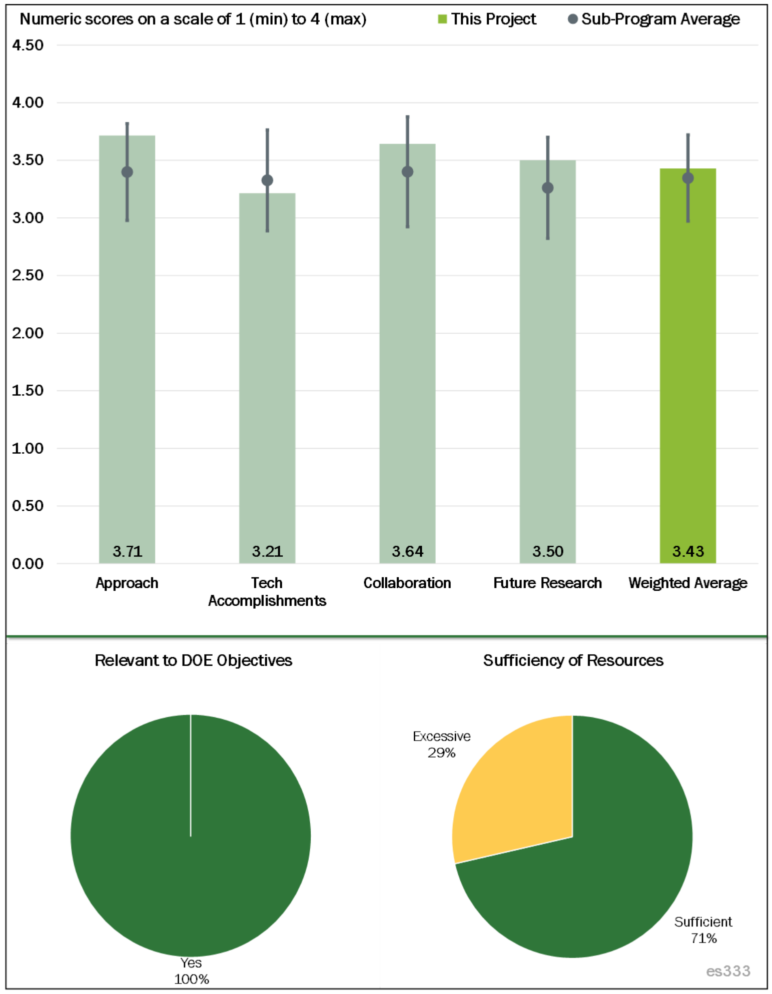

Figure 3-73 - Presentation Number: es333 Presentation Title: Silicon Electrolyte Interface Stabilization Focus Group Principal Investigator: Anthony Burrell (National Renewable Energy Laboratory)

Presenter

Anthony Burrell, National Renewable Energy Laboratory

Reviewer Sample Size

A total of seven reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

This reviewer observed an outstanding approach that addresses calendar life and cycle life issues.

Reviewer 2:

The reviewer recounted that the team is proposing to understand the fundamental issues for Si anode first before proposing new solutions to address them. It was noted by this reviewer that standard protocols for materials synthesis and characterizations are established in the first year and validated through round robin sample analysis. The reviewer opined that this effort is urgently needed in battery research and appreciated.

Reviewer 3:

This is a critical—but unrecognized—issue, asserted this reviewer. Additionally, the reviewer commented that irreproducibility in the Si electrode field is significant, and Burrell is attacking that through a very careful source identification.

Reviewer 4:

The reviewer explained that the approach to understand now and develop a fix based on that understanding is prudent and suitable for DOE work. Understanding the chemical makeup and properties is important; also important is recognizing that it may be different on Si and Si composite and SiO_x.

Reviewer 5:

The reviewer indicated that this well-designed project is appropriate for bridging the gap between fundamental characterization of surfaces and performances of particulate-containing electrodes. By using flat surfaces treated with different materials, advanced characterization methods can best resolve interfacial structures, and performance in cycling provides a link to the application.

Reviewer 6:

This reviewer described the approach as fundamentally sound. It would have been useful for this reviewer to have an organizational chart-type of slide that summarized activities occurring at each laboratory/University. The reviewer continued that such a slide would better showcase that there is, presumably, minimal duplication of effort simply from having a larger team with more researchers involved. The most promising technical approach observed was incorporation of plasma spray generated Si nanoparticles, but this reviewer strongly advised including industry partners capable of producing this material, rather than it being made at NREL alone. Similarly, because buying powders "off the shelf" may not lead to repeatable results (or even starting materials) in the future, the reviewer recommended attempting to incorporate industrial manufacturers and having the team oversee real production processes to support the synthesis of quality, reproducible materials with known properties.

Reviewer 7:

This reviewer commented that there seems to be considerable overlap both in terms of project scope and participants between this project and several other projects, noticeably ES261, ES262, and ES335. The reviewer also noted the following observations: the connection is tenuous between planned measurements on Si single crystals and nanoparticle Si-electrodes because SEIs are expected to be different; the mechanical properties of SEIs, which are known to be important, are overlooked; the advantages of the "Standard Cell Design" over the other three electrode cell designs are unproven; and the ability to make Si nano particles of more than a few nm in diameter by the RF-Enhanced Plasma Reactor method (L.M. Wheeler et al. Chem. Mater. 2015, 27, 6869) is also unproven.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This reviewer observed significant progress in this project with a coordinated effort among national labs. Identifying appropriate team members helps lead to success in this project. The reviewer agreed that "understand first, fix it later" is the right way to proceed with improving performance in these electrodes.

Reviewer 2:

Although the project just began, the reviewer noted that progress is being made.

Reviewer 3:

This reviewer remarked that it is still very early in this project.

Reviewer 4:

The reviewer indicated that most of the results are preliminary and inconclusive, probably because the project is relatively new.

Reviewer 5:

This reviewer provided the following observations of the project team: developed and validated protocols; testing lab to lab error; generated Si nanocrystals from silane (i.e., high purity) and showed they were quite reactive with standard electrolyte and even reactive with coated Si; and starting to understand the composition. While good work, the reviewer indicated that for nearly four million dollars and five labs, it seems a bit slow; it will probably speed up in the coming year now that the project team is rolling.

Reviewer 6:

The reviewer noted that the team developed standard testing protocols for effective evaluation of new materials and methods. Good progress has been demonstrated with focused areas defined. The reviewer's only concern is that there are already many published results on Si and its interfaces. The project needs to avoid a rehash of what has been known on the fundamental understandings. This reviewer recommended that more effective solutions be proposed to address the challenges.

The reviewer added that model Si anode is very important, and observed the team has selected at least three different materials for round robin tests. This is very critical to ensure that results are consistent among different teams. The reviewer expressed interest in the differences between materials tested in the project and currently adopted by industry. Although the model materials are for fundamental understanding only, the reviewer inquired whether the knowledge will be directly transferrable to the practical applications. Further, this reviewer cautioned that the strategy to scale up plasma synthesis of Si nanocrystals using SiH_4 needs to be carefully considered.

The reviewer explained that SEI on Si largely depends on the electrolyte and additives used in addition to Si surface, and suggested more electrolyte work to speed up the progress. This reviewer also advised that effective electrolyte recipes be developed and understood before throwing all kinds of characterization onto the system.

Reviewer 7:

The reviewer highlighted that the statement of work and associated deliverable cells to validate 10+ year life and 1,000 DST cycle life are not documented in the plan.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

This reviewer observed clear evidence of collaboration and coordination, especially between ORNL and NREL.

Reviewer 2:

The reviewer noted that the team has frequent communications and shares information to accelerate the research. Materials tested are from the same source and use the same protocol, ensuring effective data analysis.

Reviewer 3:

This reviewer described this effort as inherently collaborative.

Reviewer 4:

The reviewer reported that samples will be circulated among different labs to determine where irreproducibility exists.

Reviewer 5:

This reviewer commented that this is a well-coordinated, but expensive project.

Reviewer 6:

The reviewer stated that all national laboratory collaboration is necessary and will help solve the problem. If the electrolyte additives provide the solution, the reviewer recommended that a Li-ion electrolyte supplier be added for collaboration.

Reviewer 7:

The role of each national laboratory and university was unclear to this reviewer, who observed a lot of repetitive work, such as measuring the same samples using "standardized protocols" and "reproducibility across the team (multiple labs)."

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.

Reviewer 1:
The reviewer remarked that Burrell has made extensive and careful plans for developing clear protocols to get highly reproducible Si results

Reviewer 2:
This reviewer noted that future work in SEI growth characterization toward establishing general rules for the effects of surface structure and composition on properties is a promising way forward.

Reviewer 3:
The reviewer described the proposed future research as sound.

Reviewer 4:
This reviewer highlighted an excellent work plan, but commented that the timing is a little vague.

Reviewer 5:
The reviewer reported that mechanical property measurements of the SEIs may be added to the future plan.

Reviewer 6:
This reviewer regarded the future work as general. The reviewer expressed that the team can specify more details on the following: the kind of new interfaces that the team is going to identify; the kind of *in situ* and *ex situ* characterizations tools that will be developed; whether these characterizations clearly quantify SEI compositions; and whether any promising additives will be employed. The reviewer indicated that characterization is mainly based on thin film electrode, and suggested future evaluation of SEI and Si properties on the thick electrodes.

Reviewer 7:
The reviewer opined that future work should include validation of calendar life and cycle life.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
Aside from general safety improvements, the reviewer noted that this project may yield the largest breakthrough toward EV adoption by completely removing range anxiety.

Reviewer 2:
This reviewer asserted that the project supports the overall DOE objectives with a focus on Si anode for high-energy and low-cost batteries. Advanced characterizations are being developed and conducted on model Si systems, which may be broadly applicable for energy storage research.

Reviewer 3:
The reviewer explained that, clearly, Si negative electrodes are an important technology area for making BEVs a cost-effective norm in America and, subsequently, displacing petroleum-based fuels.

Reviewer 4:
This reviewer commented that improving LIB performance will enable increased utilization of fluctuating renewables and decrease reliance on petroleum.

Reviewer 5:
The reviewer relayed that the advanced anode will help meet USABC criteria and replace ICE vehicles with Li-ion EVs.

Reviewer 6:
This reviewer described this project's relevance as okay.

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

Reviewer 1:
This reviewer remarked that the national laboratories have more than sufficient, advanced tools to conduct the work. The PI has made a good plan on the task assignment and a single team works on a single goal to avoid overlap.

Reviewer 2:
Resources appeared sufficient to this reviewer. For example, the PIs were able to supply all labs with the same materials, which is an important factor in conducting consistent experiments.

Reviewer 3:
The reviewer described the project resources as okay.

Reviewer 4:
This reviewer commented that $3.9 million and about 40 researchers should be enough to troubleshoot and fix problems.

Reviewer 5:
Resources should be more than adequate, opined this reviewer, provided that industrial participation is planned.

Reviewer 6:
This reviewer observed a highly funded program and good work, but expected more at this resource level. The reviewer expressed hope of seeing more progress next year, budget allowing.

Reviewer 7:
The reviewer cautioned that there seems to be considerable overlap between this and several other DOE VTO projects.

Presentation Number: es334
Presentation Title: Insights from Mesoscale Characterization Guides Rational LIB Design
Principal Investigator: William Chueh (Stanford University)

Presenter

William Chueh, Stanford University

Reviewer Sample Size

A total of four reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

What a wonderful project. This reviewer thought the approach was fantastic, the results very new and compelling, and the PI gave a wonderful talk. This person had nothing to say except the best things about this project and thinks it will open the doors to rethinking how we model batteries.

The PI's presentation was excellent and this reviewer enjoyed following it. The PI's approach is very

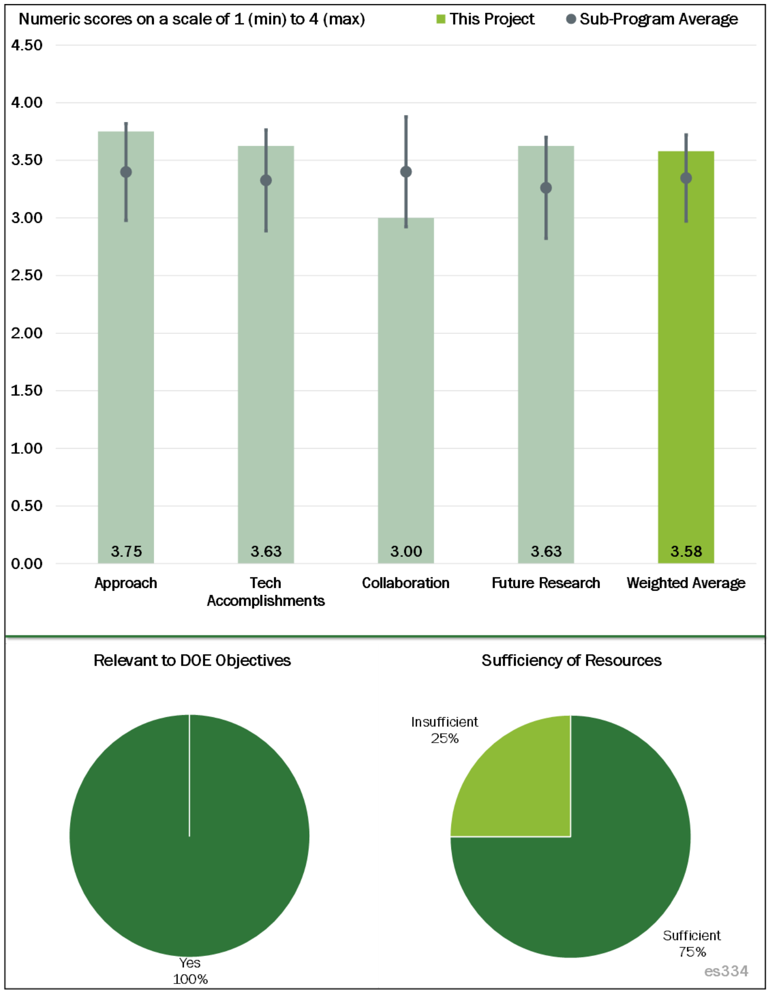

Figure 3-74 - Presentation Number: es334 Presentation Title: Insights from Mesoscale Characterization Guides Rational LIB Design Principal Investigator: William Chueh (Stanford University)

Reviewer 2:

The reviewer applauded the approach as outstanding.

Reviewer 3:

According to the reviewer, the PIs try to correlate the microstructure and local crystal structure and chemistry to the electrochemical performance of battery material taking the advantages of X-ray spectro-microscopy. The reviewer stated that the approach is very fundamental for the understanding of the root cause of many problems associated with battery active materials.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

The reviewer commended the excellent accomplishments across the board.

Reviewer 2:
The PIs provided concrete experimental evidence showing the anisotropic chemical expansion for all layered materials, including oxide and graphite, the source of non-uniform strain for the secondary particles. In this reviewer's opinion, the results could be beneficial for the material synthesis, especially co-precipitation synthesis.

Reviewer 3:
The quality and quantity of the PI's work is very high and the PI presented a number of conclusions. The reviewer would have liked to see the PI better describe which conclusions were new and which confirmed previous work in the literature by other researchers.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that the PI has several collaborations with LBNL and Samsung.

Reviewer 2:
This reviewer would highly encourage the PI to expand collaboration to other groups that have been working on this class of cathode materials for many years. There is a large group in the DOE ABR program actually called High-Energy, High-Voltage (HEHV) cathode material R&D. The reviewer thought it would be valuable for the PI to collaborate with them.

Reviewer 3:
The PIs have adequate collaboration with LBNL and Samsung. The reviewer encouraged the PIs to collaborate more with the institutions strong in electrochemical analysis and material synthesis.

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.

Reviewer 1:
The proposed future work will expand the current accomplishments. The reviewer understands that the PI will investigate the stress profile and preferred orientation of material primary and secondary particles, especially to relate the fundamental studies to the real performance of the materials.

Reviewer 2:
The reviewer stated that there is little detail, but the project generally extends present studies.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
As with other projects attacking the issues with HEHV cathode degradation mechanisms, the relevance of this work is very high in this reviewer's opinion.

Reviewer 2:
The reviewer commented that the capacity or voltage fade is critical to the development of long cycle life LIB systems.

Reviewer 3:
The reviewer stated that the work 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 are sufficient in this reviewer's opinion.

Reviewer 2:
The reviewer commented that it is very reasonable funding for the work performed.

Reviewer 3:
The reviewer noted that the PIs have adequate resources for the proposed project.

Presentation Number: es335
Presentation Title: Next-Generation Anodes for Lithium-Ion Batteries: Materials Advancements
Principal Investigator: Zhengcheng Zhang (Argonne National Laboratory)

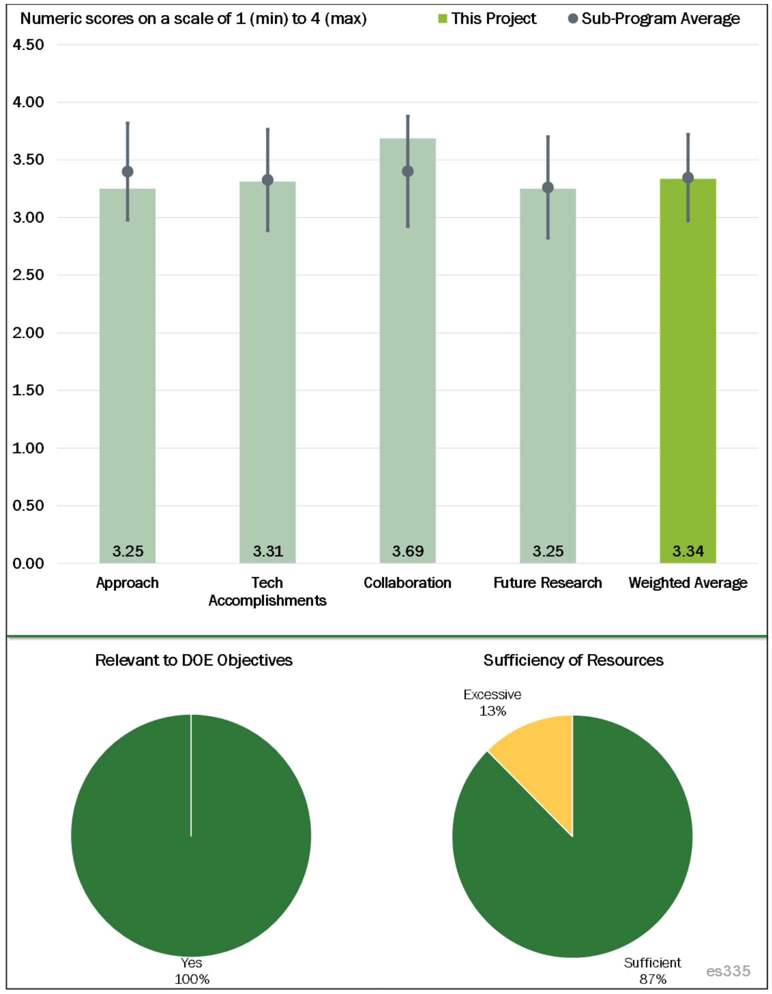

Figure 3-75 - Presentation Number: es335 Presentation Title: Next-Generation Anodes for Lithium-Ion Batteries: Materials Advancements Principal Investigator: Zhengcheng Zhang (Argonne National Laboratory)

Presenter

Zhengcheng Zhang, Argonne National Laboratory

Reviewer Sample Size

A total of eight reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:

The reviewer applauded the excellent, thorough approach to understand and develop new anode material.

Reviewer 2:

The program does an excellent job at looking at a frontier material, SI-tin (Si-Sn), for anodes. It then addresses a critical issue, the binder, in a way this reviewer finds interesting.

Reviewer 3:

The X-ray diffraction pattern of "amorphousSi0.64Sn0.36" shows multiple relatively sharp peaks. The material appears to be crystalline, not amorphous. The PI overlooked the mechanical properties and adhesion between polymer binder molecules and Si, in this reviewer's opinion.

Reviewer 4:

This project addresses the technical barriers in a Si anode by systematically studying the functional binders, atomic layer coatings (at electrode level), electrolyte/additive screening Li inventory. The reviewer commented that the project is well-designed and integrated with other team efforts. While Si itself is very challenging, it is not clear if a Si-Sn alloy will mitigate the problem because SEI on either Si or alloy are instable, but is the key parameter that dictates the electrochemical behaviors. The reviewer states the team may consider the adoption of SiO_x (with graphite) in addition to Si, which is currently what industry is using. Although the PI conducts and compares three different thickness of MLD coating, all of the Si loadings in the electrodes coated reside in "thin-film" i.e., less than 1 mg/cm^2 loading. Therefore, it was hard for this reviewer to tell if MLD coating is still effective at the electrode level.

Reviewer 5:

The Sn-coated Si particles provide an improvement in performance compared to uncoated Si. The approach to studying grafting poly acrylic acid (PAA) onto chitosan compared to linear analogs provides comparable studies of similar materials with potentially different mechanical properties, but it is unclear to this reviewer why the PI chose certain functionalities. It is also unclear to this reviewer if there is a rational design behind the targets in the polysiloxane project and what the PIs intend to learn from the structural variations.

Reviewer 6:

There seem to be too many approaches to this project to yield important results in the time allotted. Also, this reviewer thought it was unclear how many people are involved in this effort.

As this reviewer understands it, the approach will involve all of the following: alternative high-energy metals: $Me_xSi_{0.66}Sn_{0.34}$ (Me: Cu, Ni, iron [Fe], Mn); interfacial modifications by ALD or MLD and *in situ* formation of robust SEI by functional electrolyte/additive; functional polymer binders for improved adhesion and performance; Li inventory to offset the large irreversible capacity of Si anode; and alternative high-energy metals: $Me_xSi_{0.66}Sn_{0.34}$ (Me: Cu, Ni, Fe, Mn). A more clear-cut approach statement would be very helpful to the reviewer.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:

This reviewer described the results on iron oxide (lithium iron oxide [LFO]) as particularly promising. The reviewer asked if the PI is sampling this material to industrial partners, and if the PI has investigated alternative, industrialized methods of pre-lithiation. It would be interesting to this reviewer to more fundamentally understand the reason for improved stability with alucone coating. The reviewer wonders if there is a difference in CE versus the uncoated sample (the graph is too zoomed out or maybe the equipment is not sensitive enough). The reviewer asked if it is stabilizing the particle structure.

Reviewer 2:

The reviewer commented that this is an extremely large project and certain areas are advancing more quickly than others. The presentation materials do not provide sufficient details on the “25 milestones” for this reviewer to have a more complete understanding of the accomplishments and progress.

Reviewer 3:

This reviewer indicated that there have been considerable accomplishments on the Sn system and on new binders. It is not clear to this reviewer that the coatings work is breaking any new ground, either in performance or in diagnostics/understanding. This reviewer is impressed that the project team is including studies of electrolyte additives and LFO.

Reviewer 4:

The reviewer noted that the performance of Si/Sn electrodes has been reported, but no results are reported for the siloxane polymers, on which numerous targets were reported. The reviewer asked if there is a beneficial effect in introducing polysiloxanes as binders.

Reviewer 5:

It was obvious to this reviewer that the team has applied much attention and effort to this project, with research directions spanning over most aspects of Si anode materials. However, the experiments seem to be still in early stage because the reviewer heard no clear conclusions presented, and saw no selection of a clear path toward a practical Si anode.

Reviewer 6:

While there were clearly a number of interesting experiments carried out, it was not clear to this reviewer that the team has drawn any conclusions regarding these experiments. There was no assessment of which of the many binders discussed were better than the others, nor was there a conclusion regarding the different metals and alloys. One particular MLD surface treatment was applied, but no statement of comparison with other materials was made. It was also not clear to this reviewer how the Li inventory results would be applied to a functioning anode.

Reviewer 7:
The team investigated quite a few different components in Si electrode, which this reviewer recognized as a large amount of effort. Dr. Zhang is a well-known expert on electrolytes and interfaces and he leads the team progress well towards the right direction. A few comments here from this reviewer for the team to consider.

The multi-grafting chitosan-g-LiPAA showed some improvement compared to PVDF and its linear analogues. However, the differences between PAA1-4 and this multi-grafting chitosan is not obvious to this reviewer. It is not clear to the reviewer if the PI has a baseline electrode to compare the electrochemical performances. Sometimes, LiPAA is compared with PPy, while sometimes it is compared between multi-grafted and linear version. The reviewer asked if there is any conclusion on which binder the team will focus on in the future.

The reviewer recommends that the team consider Li inventory in Si anode and the team proposed using anti-fluroite type Li_5FeO_4 as the Li-inventory additive. The reviewer is uncertain whether the extra Li+ source from LFO will be stored in the anode side or trapped during the oxidation reaction on the cathode and stated that the team needs to conduct more work in order to make a go/no-go decision here.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer understands it takes a huge effort to make teams run well and collaborate effectively. The PI has done a great job in terms of collaboration within ANL and with other institutions. In the reviewer's opinion, the PI's strong electrolyte expertise and work will provide valuable information to the team and move the program move forward.

Reviewer 2:
It appeared to this reviewer that the institutions work well together.

Reviewer 3:
Many workers and laboratories were indicated, but the effort of all these collaborators was not clear to this reviewer.

Reviewer 4:
There was an enormous list of contributors and very nice intra-laboratory coordination, but the reviewer saw no indication what their level of contribution was.

Reviewer 5:
The reviewer thought the project could be further enhanced by collaborating with experts outside the national laboratories, especially in the area of mechanical measurements, including coupled electrochemical-mechanical properties and interface adhesion.

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.

Reviewer 1:
Proposed research on scale-up of some materials and testing others in full cells are reasonable next steps. This reviewer was not sure what convergent/divergent means (the reviewer saw this on the slides after visiting the poster) and how it is beneficial to project design.

Reviewer 2:
Future research directions are mainly aimed at continuing what the project team is doing. The reviewer would have preferred to see some new ideas here. The scaling up production is good.

Reviewer 3:
This statement of future research has the same problem as the accomplishments in this reviewer's opinion, in that there does not seem to be an evaluation of results that will lead to future experiments to validate or extend the promising results while discarding the unpromising ones.

Reviewer 4:
This reviewer noticed that one of the "Remaining Challenges and Barriers" of "Particle cracking, particle isolation, and electrode delamination" is not addressed under "Future Work."

Reviewer 5:
Future plans mention a divergent/convergent approach of multiple exploratory paths. However, it is not clear to this reviewer if the plans include a more iterative approach toward screening and improving materials, which should allow an earlier focus on fewer candidates.

Reviewer 6:
The PI will consider full cell format testing in the future, which will be very critical for Si evaluation. ANL has strong capabilities on characterization which will help identify the structure-property relationship for Si-based electrodes. It is not clear to this reviewer if SiO_x will be included in the future work. The reviewer would like the PI to justify why Si-Sn alloy is being studied at the same time, considering either Si or Sn is challenging when there is still no clue about the electrolytes/additives. Before scaling up any new materials such as MLD coating or binder synthesis, the reviewer recommended confirming the effectiveness of these new materials in full cells. The PI may need to consider the cost of MLD coating as well.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
This project is highly relevant to DOE objectives to develop high-energy battery technologies for vehicle electrification. Electrolytes, additives, binders and Li inventory are all critical for the success of high-performance Si anode in this reviewer's opinion.

Reviewer 2:
The reviewer noted that high-energy anodes are clearly relevant.

Reviewer 3:
This reviewer is especially interested in the work on additives and LFO.

Reviewer 4:
The reviewer said yes and commented that improving the LIB performance will allow for a greater incorporation of renewable energy sources.

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 for the project appear to be sufficient.

Reviewer 2:
The reviewer found the resources okay.

Reviewer 3:
The reviewer suggested adding mechanical property measurements.

Reviewer 4:
In this reviewer's opinion, ANL, along with other national laboratories, has more than sufficient facilities and resources to conduct the proposed research and meet the milestones.

Presentation Number: es336
Presentation Title: Extreme Fast Charging (XFC) Gap Assessment
Principal Investigator: Christopher Michelbacher (Idaho National Laboratory)

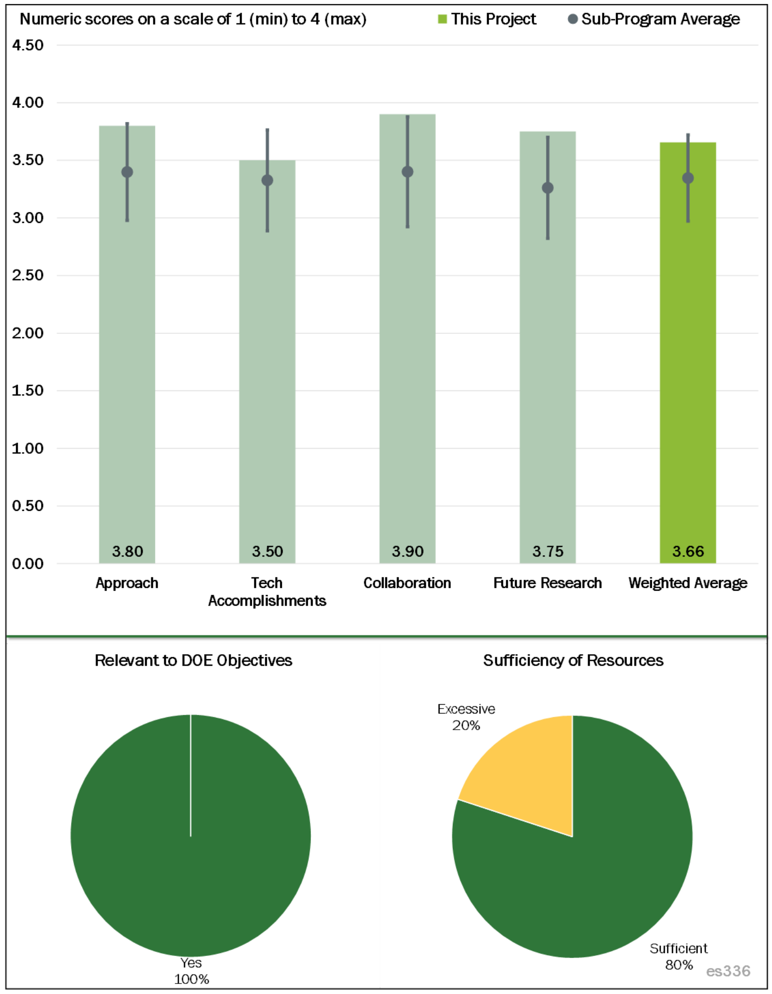

Figure 3-76 – Presentation Number: es336 Presentation Title: Extreme Fast Charging (XFC) Gap Assessment Principal Investigator: Christopher Michelbacher (Idaho National Laboratory)

Presenter
Christopher Michelbacher, Idaho National Laboratory

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Reviewer 1:
This is a very good approach to getting into a new subject. This is an excellent precursor to any new area of research, in this reviewer's opinion.

Reviewer 2:
The reviewer noted that the project reached out to the key stakeholders to help outline the issues and needs, involved technology experts, and reviewed the impact from a cost perspective.

Reviewer 3:
The reviewer commented that stakeholder meetings, collaboration among the national laboratories, literature search, and a case study are very effective and comprehensive approaches to understand the technical gaps for enabling fast charging.

Reviewer 4:
This reviewer thought that most technical barriers have been identified. There might not be clear solutions for all of them, but in this reviewer's understanding, identifying the barriers was the primary goal of the program, which the reviewer believes was accomplished.

Question 2: Technical accomplishments and progress toward overall project and DOE goals—the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Reviewer 1:
The reviewer said excellent, and that the results basically confirm most peoples' intuition about the issues with XFC but the reviewer found it reassuring to see that done with actual data.

Reviewer 2:
The team demonstrated excellent accomplishments in the four key areas of concern. On the technical side these areas were the battery, the vehicle, and the infrastructure. Additionally, the team also considered economic feasibility and compared the effect of charge rate against several key cell metrics and tabulated. All of these data meet the goals of the project in the reviewer's opinion.

Reviewer 3:
The reviewer stated that this investigation provides clear, concise answers to a range of problems facing fast-charging, including battery technology, vehicle design, economics and infrastructure.

Reviewer 4:
This is a very thorough project, looking at all aspects of XFC. The reviewer noted that the data were studied from multiple angles and at each level affected by XFC, from cells and batteries to charging infrastructure and economics.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer found very good involvement of all involved parties, including national laboratories, battery manufacturers, charger manufactures, and automotive OEMs.

Reviewer 2:
The reviewer noted that automotive OEMs, battery suppliers, utility suppliers, electric vehicle supply equipment (EVSE) manufacturers, and all key players, were involved and contributed.

Reviewer 3:
The reviewer commented that this work involves the close collaboration of three national laboratories, and solicited inputs from wide variety of related industries.

Reviewer 4:
The reviewer stated that the team included many potential stakeholders in discussions.

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.

Reviewer 1:
The reviewer liked that there is no future work because the project is complete. The reviewer hoped we can encourage the majority of PIs to "finish" projects when they reach their objectives, and then propose to move on to new or modified subjects.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer said yes, and commented that this work provides guidance to the VTO to prioritize its R&D activities.

Reviewer 2:
This project is to help develop technology that will relieve consumer "range anxiety" and allow for easier adoption of the technology in this 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:

Everything about this project was excellent. This reviewer’s impression is that the cost was on the high side, but still an excellent project and end product.

Reviewer 2:

The reviewer noted that the program has ended and the data provided were complete.

Reviewer 3:

The resources are sufficient for this amount of work in this reviewer’s opinion. The money is distributed to three national laboratories based on effort.

Acronyms and Abbreviations

°C	Degrees Celsius
3D	Three-dimensional
A	Ampere
ABR	Advanced Battery Research
AFM	Atomic force microscopy
Ah	Ampere-hour
Al	Aluminum
Al_2O_3	Aluminum oxide
ALD	Atomic layer deposition
AlF_3	Aluminum fluoride
AMR	Annual Merit Review
ANL	Argonne National Laboratory
ARL	Army Research Laboratory
ATR	Attenuated total reflectance
BEV	Battery electric vehicle
BMR	Battery Materials Research
BNL	Brookhaven National Laboratory
C	Carbon
CABS	Consortium for Advanced Batteries Simulation
CAE	Computer-aided engineering
CAEBAT	Computer-aided engineering of batteries
CAMP	Cell Analysis, Modeling, and Prototyping Facility
CB	Carbon black
CCD	Critical current density
CE	Coulombic efficiency
CEI	cathode electrolyte interfacial
cm	Centimeter

CMC	Carboxymethyl cellulose
Co	Cobalt
CO_2	Carbon dioxide
Co-Ex	Co-extrusion
CPE	Composite polymer electrolytes
Cu	Copper
CuF_2	Copper (II) Fluoride
DEC	Diethyl carbonate
DEMS	Differential electrochemical mass spectroscopy
DFT	Density functional theory
DNS	Direct numerical simulation
DOE	Design of experiments
DOE	U.S. Department of Energy
DST	Dynamic stress test
EB	Electron beam
EDS	Energy dispersive spectroscopy
EERE	Energy Efficiency and Renewable Energy
EM	Electron microscopy
EOL	End-of-life
EV	Electric vehicle
Fe	Iron
FEA	Finite element analysis
FEC	Fluoroethylene carbonate
FTIR	Fourier transform infrared
FY	Fiscal year
GM	General Motors
HA	High active
HEV	Hybrid electric vehicle

HPC	High-performance computing
HRTEM	High-resolution transmission electron microscopy
HXN	Hard X-ray nano-probe
ICE	Internal combustion engine
IL	Ionic liquid
INL	Idaho National Laboratory
IP	Intellectual property
kg	Kilogram
kWh	Kilowatt-hour
l	Liter
LBNL	Lawrence Berkeley National Laboratory
LCO	Lithium cobalt oxide
LFO	Lithium iron oxide
LFP	Lithium iron phosphate
Li	Lithium
Li_3PO_4	Lithium phosphate
LIB	Lithium-ion battery
$LiCoO_2$	Lithium cobalt oxide
LiFSI	Lithium bis(flurosulfonyl)mide
Li-ion	Lithium Ion
$LiPF_6$	Effective electrolyte salt for lithium-ion battery
LiPON	$Li_{2.88}PO_{3.86}N_{0.}14$
Li-S	Lithium-sulfur
LL	Layered-layered
LLS	Layered-layered spinel
LLZO	Lithium lanthanum zironate
LMNO	Lithium manganese nickel oxide
LMO	Lithium manganese oxide

LMR	Lithium manganese rich
LNMO	Lithium nickel manganese oxide
LTO	Lithium titanium oxide
M&S	Modeling and simulation
mA	Milliampere
MD	Molecular dynamics
MERF	Materials Engineering Research Facility
MLD	Molecular layer deposition
Mn	Manganese
MRI	Magnetic resonance imaging
NCA	Battery cathode material (nickel cobalt aluminum oxide)
NCM	Nickel cobalt manganese oxide
NHTSA	National Highway Traffic Safety Administration
Ni	Nickel
NMC	Nickel manganese cobalt oxide
NMO	Nickel manganese oxide
NMP	N-methylpyrrolidone
NMR	Nuclear magnetic resonance
NREL	National Renewable Energy Laboratory
NSLSII	National Synchrotron Light Source II
NYBEST	New York Battery and Energy Storage Technology Consortium
O_2	Oxygen
OAS	Open architecture software
OEM	Original equipment manufacturer
ORNL	Oak Ridge National Laboratory
OS	Organosilicon
PAA	Polyacrylic acid
PDF	Paired distribution function

PHEV	Plug-In hybrid electric vehicle
PI	Principal investigator
PNNL	Pacific Northwest National Laboratory
PPy	Polypyrrole
PSD	Particle size diameter
PVDF	Polyvinylidene difluoride
R&D	Research and development
RPT	Reference performance test
S	Sulfur
SBIR	Small Business Inngovation Research
SEI	Solid electrolyte interface
Si	Silicon
Si-C	Silicon Carbon
SiO_x	Silicon oxide
SLAC	Stanford Linear Accelerator Center
SME	Subject matter expert
Sn	Tin
SNL	Sandia National Laboratories
SOA	Semiconductor optical amplifier
SOC	State of charge
SRL	Surface reconstruction layer
$SrTiO_3$	Strontium titanate
SSRL	Stanford Synchrotron Radiation Lightsource
STEM	Scanning transmission electron microscopy—electron energy loss spectroscopy
SUNY	State University of New York
SWCNT	Single wall carbon nanotube
TEA	Technology-Economic Analysis
TEM	Transmission electron microscopy

TEY	Total electron yield
TM	Transition metal
TRL	Technology Readiness Level
TXM	Transmission X-ray microscopy
U.S.	United States
UIC	University of Illinois at Chicago
USABC	United States Advanced Battery Consortium
UV	Ultraviolet
V	Volt
VC	Vinylene carbonate
VOPO4	Vanadium phosphate
VTO	Vehicle Technologies Office
W	Watt
WFO	Work-for-others
Wh	Watt hour
Wh/l	Watt hour per liter
XANES	X-ray absorption near edge structure
XAS	X-ray absorption spectroscopy
XFC	Extreme fast charging
XPD	X-ray powder diffraction
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction
µ	Micron