4. Electrification Technologies

To strengthen national security, promote future economic growth, support American energy dominance, and increase transportation energy affordability for Americans, the Vehicle Technologies Office (VTO) funds early-stage, high-risk research. This research will generate knowledge that industry can advance to deploy innovative energy technologies to support affordable, secure, reliable, and efficient transportation systems across America. VTO leverages the unique capabilities and world-class expertise of the National Laboratory system to develop new innovations in electrification, including advanced battery technologies; advanced combustion engines and fuels, including co-optimized systems; advanced materials for lighter-weight vehicle structures and better powertrains; and energy efficient mobility technologies and systems, including automated and connected vehicles as well as innovations in connected infrastructure for significant systems-level energy efficiency improvement. VTO is uniquely positioned to address early-stage challenges due to its strategic research partnerships with industry (e.g., the U.S. DRIVE and 21st Century Truck Partnerships) that leverage relevant technical and market expertise. These partnerships prevent duplication of effort, focus DOE research on the most critical research and development (R&D) barriers, and accelerate progress. The partnerships help VTO focus on research that industry does not have the technical capability to undertake on its own—usually because there is a high degree of scientific or technical uncertainty or it is too far from market realization to merit sufficient industry emphasis and resources. At the same time, VTO works with industry to ensure there are pathways for technology transfer from government to industry so that Federally-supported innovations have an opportunity to make their way into commercial application.

The Electrification R&D effort focuses on early-stage research to support fast, secure, and resilient plug-in electric vehicle (PEV) charging on the nation's electric grid. Specifically, projects will increase the reliability of charging by focusing on smart-charging technology to support secure and cost-effective charging of large volumes of PEVs. Research will also focus on extreme fast-charging at power levels greater than 350 kW to support charging a PEV in 10–15 minutes and support heavy-duty truck charging as well. Impacts of PEV charging at scale for light-, medium-, and heavy-duty vehicles will be minimized through technologies that provide better flexibility and control, such as wireless charging approaches and chargers that use distributed energy resources, further supporting the Grid Modernization Initiative (GMI) and leveraging developments in battery energy storage technologies through the Behind the Meter Storage (BTMS) effort.

Electric Drive Research conducts R&D to reduce the cost of electric traction drive systems that can deliver at least 55kW of peak power to $7/kW by 2022, enabling cost-competitive technologies for vehicle electrification. Early-stage research focuses on extreme high power density motor and power electronics technologies that have the potential to support radical new vehicle architectures by dramatic volume/space reductions and increased durability and reliability. This work emphasizes a 10-fold reduction in the volume of electric traction drive systems, which combine power electronics and motors using high-density integration technologies. Approaches include wide bandgap devices, dense power electronics packaging, novel circuit topologies, and new materials for high-density electric motors. Electric traction drive system integration based on power electronics and electric motor innovations are also be a priority.

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 4-1 – Project Feedback

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
elt089	Assessing the North American Supply Chain for Traction-Drive Inverters, Motors, and Batteries for Class 3-8 Hybrid Electric and Plug-In Electric Commercial Vehicles	Chris Whaling (Synthesis Partners)	4-7	3	2.83	3.33	2.33	2.88
elt090	Dual-Phase, Soft Magnetic Laminates for Low-Cost, Non-Reduced Rare-Earth Containing Electrical Machines †	PR Subramanian (GE Global Research)	4-11	3.5	3.5	3.5	3.38	3.48
elt091	Cost-Effective 6.5% Silicon Steel Laminate for Electric Machines †	Jun Cui (Iowa State University)	4-14	3.38	3.25	3.5	3.25	3.31
elt092	Wound Field and Hybrid Synchronous Machines for Electric Vehicle Traction with Brushless Capacitive Rotor Field Excitation	Ian Brown (Illinois Institute of Technology)	4-17	3.25	3.38	3.38	3.38	3.34
elt093	High-Speed Hybrid Reluctance Motor with Anisotropic Materials	Edwin Chang (General Motors)	4-20	3.25	3.13	3.25	3	3.16
elt094	Development and Demonstration of Medium- and Heavy-Duty Plug-In Hybrid Work Trucks	John Petras (Odyne Systems)	4-23	3.25	2.75	3	2.63	2.89

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
elt095	Vehicle-to-Grid Electric School Bus Commercialization Project	Dennis Whitaker (Blue Bird Corp.)	4-28	2.9	3	2.7	2.7	2.9
elt158	Zero-Emission Cargo Transport II: San Pedro Bay Ports Hybrid & Fuel-Cell Electric Vehicle Project	Joseph Impullitti (SCAQMD)	4-34	3.4	3.3	3.3	3	3.29
elt187	Comprehensive Assessment of On- and Off-Board, Vehicle-to-Grid Technology Performance and Impacts on Batteries and the Grid	Sunil Chhaya (EPRI)	4-39	3.4	3.4	3.4	3.3	3.39
elt188	Bi-Directional Wireless Power Flow for Medium-Duty Vehicle-to-Grid Connectivity	Steven Sokolsky (CALSTART)	4-43	3.67	3.33	3.25	3.17	3.39
elt189	Electric Truck with Range-Extending Engine (ETREE)	John Kresse (Cummins)	4-48	3.63	3.25	3.5	3.25	3.38
elt190	Medium-Duty Urban Range Extended Connected Powertrain (MURECP)	Alexander Freitag (Bosch)	4-52	3.5	3.17	3.5	3	3.27
elt191	Medium-Duty Vehicle Powertrain Electrification and Demonstration	Wiley McCoy (McLaren)	4-55	3.2	3.2	3.5	3	3.21
elt197	High Power and Dynamic Wireless Charging of Electric Vehicles (EVs)	Veda Galigekere (ORNL)	4-59	3.1	3.3	3.5	3.1	3.25
elt198	Cybersecurity: Securing Vehicle Charging Infrastructure - SNL	Jay Johnson (SNL)	4-63	3.5	3.42	3.25	3.25	3.4
elt199	Cybersecurity: Consequence-Driven Cybersecurity for High-Power Charging Infrastructure -INL	Richard Carlson (INL)	4-69	3.5	3.38	3	3.25	3.34

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
elt200	Scalable Electric Vehicle Smart Charging Using Collaborative Autonomy	Steve Chapin, Jovanna Helms; (LLNL)	4-72	3	3	2.5	3	2.94
elt201	Charging Infrastructure Technologies: Smart Vehicle-Grid Integration - ANL	Keith Hardy (ANL)	4-76	3.67	3.33	3.83	3.5	3.5
elt202	Charging Infrastructure Technologies: Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE) - NREL	Kevin Walkowicz (NREL)	4-79	3.33	3.17	3.25	3.33	3.24
elt204	Charging Infrastructure Technologies: Development of a Multiport, ≥1 MW Charging System for Medium- and Heavy-Duty Electric Vehicles - NREL	Kevin Walkowicz (NREL)	4-84	3.5	3.13	3.25	3.13	3.23
elt205	Cybersecurity for Grid Connected eXtreme Fast Charging (XFC) Station (CyberX)	Junho Hong (ABB)	4-88	2.63	2.75	3.13	3	2.8
elt206	Cybersecurity Platform and Certification Framework Development for XFC-Integrated Charging Infrastructure Ecosystem	Tobias Whitney (EPRI)	4-91	3.2	2.9	3.3	3	3.04
elt207	Enabling Secure and Resilient XFC: A Software/Hardware Security Co-Design Approach	Ryan Gerdes (Virginia Tech)	4-95	3.5	2.8	3.1	3.5	3.1
elt208	Highly Integrated Power Module	Emre Gurpinar (ORNL)	4-99	3.38	3.25	3.63	3.5	3.36
elt209	High-Voltage, High-Power Density Traction Drive Inverter	Gui-Jia Su (ORNL)	4-102	3.25	3.13	3.13	3.25	3.17

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
elt210	Development of Next-Generation Vertical Gallium-Nitride Devices for High-Power Density Electric Drivetrain	Greg Pickrell (SNL)	4-105	3.67	3.17	3.67	3.17	3.35
elt211	Power Electronics Thermal Management	Gilbert Moreno (NREL)	4-108	3.4	3.2	3.1	3.1	3.23
elt212	Non-Heavy Rare-Earth High-Speed Motors	Tsarafidy Raminosoa (ORNL)	4-112	3	2.5	2.5	3	2.69
elt213	High-Fidelity Multiphysics Material Models for Electric Motors	Jason Pries (ORNL)	4-114	2	2	3	2.5	2.19
elt214	Electric Motor Thermal Management	Kevin Bennion (NREL)	4-116	2.75	2.88	2.63	2.88	2.81
elt215	Permanent Magnets without Critical Rare Earths to Enable Electric Drive Motors with Exceptional Power Density	Iver Anderson (Ames Laboratory)	4-119	3	3	2.75	3.13	2.98
elt216	Isotropic, Bottom-Up Soft Magnetic Composites for Rotating Machines	Todd Monson (SNL)	4-122	2.88	3.13	2.88	2.63	2.97
elt217	Integrated/Traction Drive Thermal Management †	Bidzina Kekelia (NREL)	4-125	3.4	3.3	2.9	3.1	3.25
elt218	Advanced Power Electronics Designs – Reliability and Prognostics †	Doug DeVoto (NREL)	4-129	3.4	3.4	3.6	3.5	3.44
elt219	Power Electronics Materials and Bonded Interfaces – Reliability and Lifetime †	Paul Paret (NREL)	4-133	3.13	3	3.13	3	3.05
elt220	Ultraconducting Copper †	Tolga Aytug (ORNL)	4-136	2.83	2.83	2.83	2.5	2.79

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
elt221	Integrated Electric Drive System †	Shajjad Chowdhury (ORNL)	4-139	3.25	3.25	3.5	3	3.25
elt222	High-Reliability Ceramic Capacitors to Enable Extreme Power Density Improvements †	Jack Flicker (SNL)	4-141	3.25	3	2.75	3	3.03
elt223	Component Testing, Co-Optimization, and Trade-Space Evaluation †	Jason Neely (SNL)	4-145	3.17	3	3.33	3.5	3.15
elt234	Soft Magnets to Achieve High-Efficiency Electric Drive Motors of Exceptional Power Density †	Matthew Kramer (Ames Laboratory)	4-148	3.25	3.25	3.25	3.25	3.25
elt235	Behind-the-Meter Storage Overview	Anthony Burrell (NREL)	4-150	3.33	3.5	3.17	3.17	3.38
elt239	High-Power Inductive Charging System Development and Integration for Mobility	Omer Onar (ORNL)	4-153	3.7	3.6	3.5	3.6	3.61
elt240	Wireless Extreme Fast Charging for Electric Trucks (WXFC-Trucks)	Mike Masquelier (WAVE)	4-157	3.5	3.13	3.63	3.5	3.33
elt241	High-Efficiency, Medium-Voltage-Input, Solid-State-Transformer-Based 400-kW/1000-V/400-A Extreme Fast Charger for Electric Vehicles	Charles Zhu (Delta Electronics)	4-160	3.17	3.33	3.5	3.17	3.29
Overall Average				**3.25**	**3.13**	**3.22**	**3.11**	**3.17**

† Denotes a poster presentation.

Presentation Number: elt089
Presentation Title: Assessing the North American Supply Chain for Traction-Drive Inverters, Motors, and Batteries for Class 3-8 Hybrid Electric and Plug-In Electric Commercial Vehicles
Principal Investigator: Chris Whaling (Synthesis Partners)

Presenter
Chris Whaling, Synthesis Partners

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 and well-planned.

Reviewer 1:
The reviewer said that overall, the approach described in the presentation looks appropriate

Reviewer 2:
The reviewer remarked the two barriers identified by the project include the need for accurate information about electric passenger and commercial vehicles (ECVs) and their component supply chains in North America; and actionable intelligence on R&D gaps that affect autonomous vehicles (AVs), electric vehicles (EVs), Class 3-8 hybrid electric vehicles (HEV)-EVs, power electronics, batteries, and motors in North America. This project clearly addresses the first barrier above and to a certain degree the second barrier, although it is not entirely clear how the information provided is "actionable." The reviewer said additional detail on how the project is making information "actionable" would have been beneficial. Additionally, one of the barriers identified during the course of the project was how to best structure heterogeneous data.

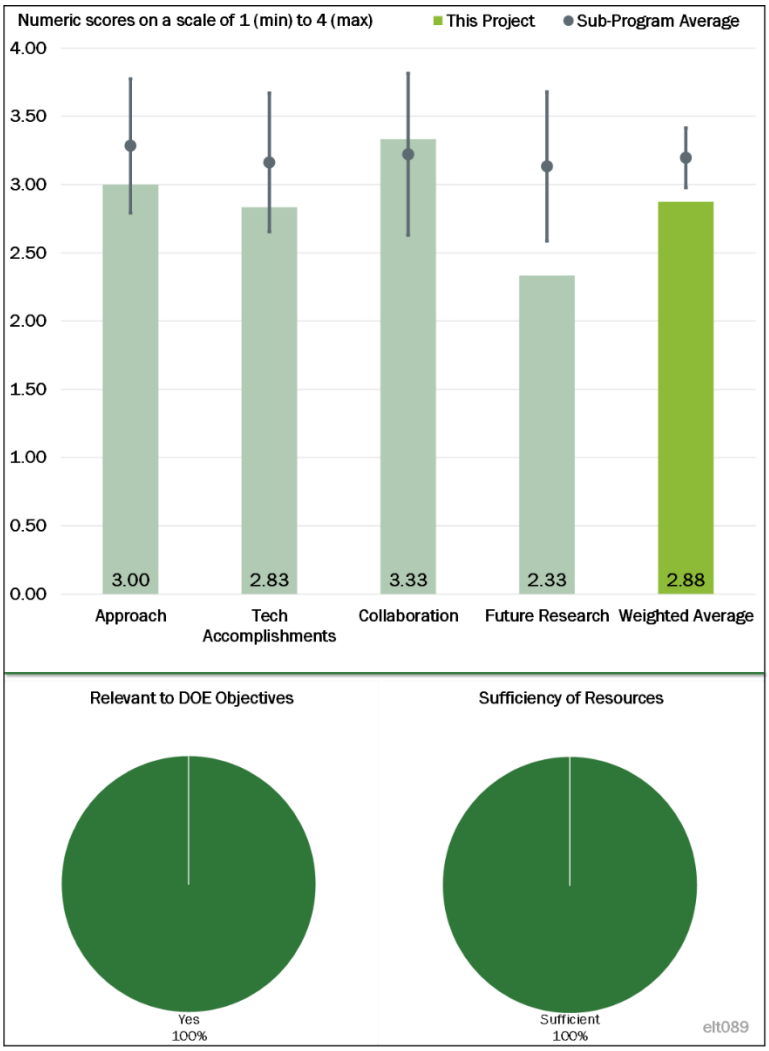

Figure 4-1 – Presentation Number: elt089 Presentation Title: Assessing the North American Supply Chain for Traction-Drive Inverters, Motors, and Batteries for Class 3-8 Hybrid Electric and Plug-In Electric Commercial Vehicles Principal Investigator: Chris Whaling (Synthesis Partners)

The reviewer detailed that the project uses a five stage approach including: developing specific customer questions with regards to their business, supply chains, future plans, technology gaps, constraints, bottlenecks, etc.; collecting data through primary (interviews) and secondary (literature) resources; modelling, including quantitative and qualitative data analysis; conducting technical analysis with regards to cost, trends, and gaps; and preparing reports. The reviewer said one focus of the project is to develop previously unidentified data and make it public, with most of the analysis being subjective and qualitative. The reviewer remarked it would have been beneficial if some additional insight into the domain modelling processes were provided. Given that much of the data collected are heterogeneous, it is likely there are a number of different paths that could have

been pursued with regards to analysis. The reviewer would have liked to have known if different potential analysis paths were explored, and if so their benefits and drawbacks, and why a specific analysis path was chosen. Overall, the approach seems solid and comprehensive.

Reviewer 3:
The reviewer said that the presentation was about what was done rather than providing findings/insights, and need specifics for the work to be effective.

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

Reviewer 1:
The reviewer pointed out that identified gaps are useful for further study to get improved and useful data for DOE

Reviewer 2:
The reviewer found that the project has made substantial overall progress. Specifically, completion of the report "Class 3-8 Hybrid and Electric Vehicles Operating on North American Roads: A Supply Chain Assessment Covering Producers of Vehicles, Drive-Train Motors, Inverters, Converters and Batteries" (January 2019). Specifically, this report includes identification of the approximate total number of class 3-8 HEVs and EVs in operation on North American roads in 2018, including a breakdown by trucks, buses, and up-fitted Class 3-8 HEV and EVs, and an estimate in operation globally. Hundreds of gap statements have been identified and collected through open-ended interviews and secondary research and broken down into the following areas: battery, inverter, motor, converter, and other (which covers manufacturability, public incentives and subsidies, regulation, standards, materials, and software). The reviewer noted that battery, motor, inverter, and converter gaps have been further broken down into areas related to engineering, costs, materials, standards, software, and Other. "Other" has been identified as an increasing important category and has identified that technology gaps require increasingly interdisciplinary RDT&E. The reviewer remarked the battery, inverter, motor, and converter manufacturers and their relative contributions to the supply chain have been identified. This is the first comprehensive Class 3-8 HEV/EV inventory that will be available publically.

Second, progress has been achieved on the ongoing North American charging infrastructure assessment. 50% completion has been achieved with hundreds of phone calls, reviews of thousands of North American EV charging electronic sources, and 360+ individuals and 140+ organizations identified.

Overall, a significant amount of research has been conducted and assimilated.

Reviewer 3:
The reviewer said that the information provided showed what was done: types of sources; methods used; general facts; etc. The work performed seemed extensive, but no real insights were provided that are needed to determine the value of the work.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer identified this as a strength of the project, and noted multiple sources and discussions.

Reviewer 2:
The reviewer pointed out that original equipment manufacturers (OEMs) and DOE National Laboratories are involved in this work led by the Synthesis Partners.

Reviewer 3:
The reviewer said the project exhibits good coordination in the sense that it has reached out to an extensive number of entities in its data collection efforts including hundreds of industry, OEMs, Tier 1-4 companies, universities, and other subject matter experts in both the public and private sectors. The project has conducted in-depth engagement with select sources at conferences. The reviewer noted consistent engagement with DOE and other Federal research laboratories has been conducted.

The reviewer noted that besides Synthesis Partners, the project does not have any other team members. It was not mentioned whether any collaboration/coordination/engagement with other similar firms or research was undertaken to explore different means of establishing the project approach and in collecting, organizing, analyzing, and presenting the data. The reviewer said in short, it may have been beneficial to seek some additional perspectives in these areas as it may have uncovered other beneficial approaches to increase the project's value add.

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 identified gaps can be a great basis for future research.

Reviewer 2:
The reviewer said the project ends in September 2019 with the completion of the report on the North American EV Charging Infrastructure Supply Chain Research, and no further proposed research has been presented.

Reviewer 3:
The reviewer said that no description of future work was provided.

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

Reviewer 1:
The reviewer said yes, this project is relevant in that it is the first independent assessment of the actual number and types of Class 3-8 HEVs and EVs operating in North America, along with their associated critical components and supply chain. In order for the Vehicle Technologies Office (VTO) to make salient decisions with regards to future HEV and EV research, it is important to have up-to-date, quantified, and validated industry/commercial information to serve as a baseline and help identify gaps that may need to be addressed.

Reviewer 2:
The reviewer remarked the project area of work should provide insights into vehicle electrification.

Reviewer 3:
The reviewer noted that it is necessary to know gaps in E-mobility supply chain followed by proper efforts placed to close those gaps. In that regard, this project is very relevant to endeavors funded by DOE-VTO and stakeholders for the outcome of 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 found that the resources for this project are sufficient. There has been a very comprehensive primary and secondary data collection effort undertaken with many sources, which can be very time consuming. A significant number and breadth of entities have been contacted and their information

assimilated, categorized, and analyzed. The reviewer noted that three separate reports will have been completed by the project's end in September 2019.

Reviewer 2:

The reviewer remarked that Synthesis Partners as the project performing entity seems to have appropriate resources, including data analytics applied on the collected information from OEMs and EV system integrators.

Reviewer 3:

The reviewer said that the effort seems to be adequate for this type of study.

Presentation Number: elt090
Presentation Title: Dual-Phase, Soft Magnetic Laminates for Low-Cost, Non-Reduced Rare-Earth Containing Electrical Machines
Principal Investigator: PR Subramanian (GE Global Research)

Presenter
Min Zou, GE Global Research

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 and well-planned.

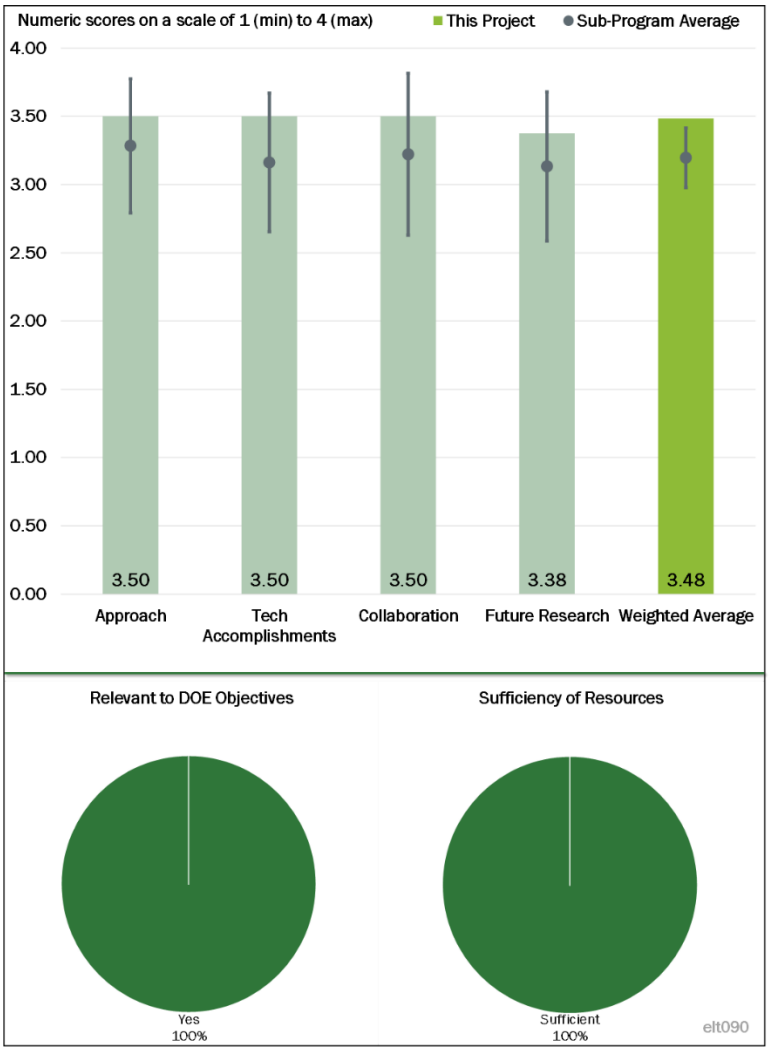

Figure 4-2 – Presentation Number: elt090 Presentation Title: Dual-Phase, Soft Magnetic Laminates for Low-Cost, Non-Reduced Rare-Earth Containing Electrical Machines Principal Investigator: PR Subramanian (GE Global Research)

Reviewer 1:
The reviewer said demonstrating manufacturability of the dual-phase magnetic laminates by fabricating a subscale prototype is feasible.

Reviewer 2:
The reviewer said the method is well-defined

Reviewer 3:
The reviewer remarked the approach of the project is focused on demonstrating and achieving the benefits of the dual-phase laminate material. The project appears to be on track to build and test a full-scale prototype with the material. The reviewer was a little unclear in terms of the cost impact of the material and how this impacts the overall motor cost.

Reviewer 4:
The reviewer commented this is an interesting project with potential assuming that volume production of the particular steel alloy grade and a not-batch nitrogenation step is achievable. While building a synchronous reluctance machine can isolate some of the performance gains achievable using the dual-phase material, it is likely that an interior permanent magnet (IPM) using the material is more feasible for traction applications. Slide 28 seems to indicate this. The reviewer remarked realistically, a pure synchronous reluctance machine is unlikely to have the power density and power factor suitable for an automotive traction application.

The reviewer asked why the flux barriers were stamped out and only the bridges made non-magnetic, and wondered why not keep the flux barriers as a non-magnetic steel region. Much higher speeds could most likely be obtained.

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

Reviewer 1:
The reviewer found the project is progressing smoothly.

Reviewer 2:
The reviewer said the project appears to have accomplished the objective to demonstrate the manufacturability of the dual-phase laminate material. A key question would be the cost impact on the overall motor.

Reviewer 3:
The reviewer asked if the volumetric and specific power densities listed on Slide 13 are only for active materials or do they include the anticipated volume and mass of the other components on Slide 14. The reviewer said the predicted power factor should be listed as part of the performance specifications on Slide 13, and the measured power factor of the sub-scale prototype should also be provided.

Reviewer 4:
The reviewer described the project as accomplished and on track to meet the goals

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said it appears that the collaboration among the project team members is going well.

Reviewer 2:
The reviewer remarked the project appears to include close collaboration with other institutions and the work is well-coordinated.

Reviewer 3:
The reviewer said the collaboration looks reasonable.

Reviewer 4:
The reviewer remarked that collaboration is well defined, but does not seem to be essential for the project completion.

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 appears to be ending soon, and the future work appears to focus on completing remaining tasks, such as the full-scale motor fabricating and testing.

Reviewer 2:
The reviewer remarked the major remaining project task is the full scale prototype assembly and testing and some material property measurements. These appear to be feasible for the remaining project period of fiscal year (FY) 2019. The reviewer hoped that there is a market development plan for the material that results in it being available.

Reviewer 3:
The reviewer remarked the project is nearly at its end, which may be out of the project scope. More funding may be required

Reviewer 4:
The reviewer asked if the project team is going to compare this machine with other rare-earth free machines such as switched reluctance machines.

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

Reviewer 1:
The reviewer said yes, well defined and executed project.

Reviewer 2:
The reviewer remarked this project does appear to support the DOE objectives in that it is focused on new materials to improve motor performance.

Reviewer 3:
The reviewer said yes, reducing the need of rare-earth materials is one of the major DOE goals.

Reviewer 4:
The reviewer commented the material and processes being developed have application to synchronous reluctance machines, permanent magnet-assisted synchronous reluctance machines, and IPM synchronous machines.

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 to be sufficient to accomplish the work and achieve the milestones.

Reviewer 2:
The reviewer commented the resources appear to be sufficient.

Reviewer 3:
The reviewer remarked resources are well covered.

Reviewer 4:
The reviewer noted that GE has sufficient resources.

Presentation Number: elt091
Presentation Title: Cost-Effective 6.5% Silicon Steel Laminate for Electric Machines
Principal Investigator: Jun Cui (Iowa State University)

Presenter
Jun Cui, Iowa State 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 and well-planned.

Reviewer 1:
The reviewer noted that the approach of the project is focused three key areas, including new magnet material development, new electrical steel development, and a motor demonstration with the materials.

Reviewer 2:
The reviewer said yes, and the project is addressing the stated technical barriers.

Reviewer 3:
The reviewer pointed out that the approach to make non-rare-earth alternatives is critical.

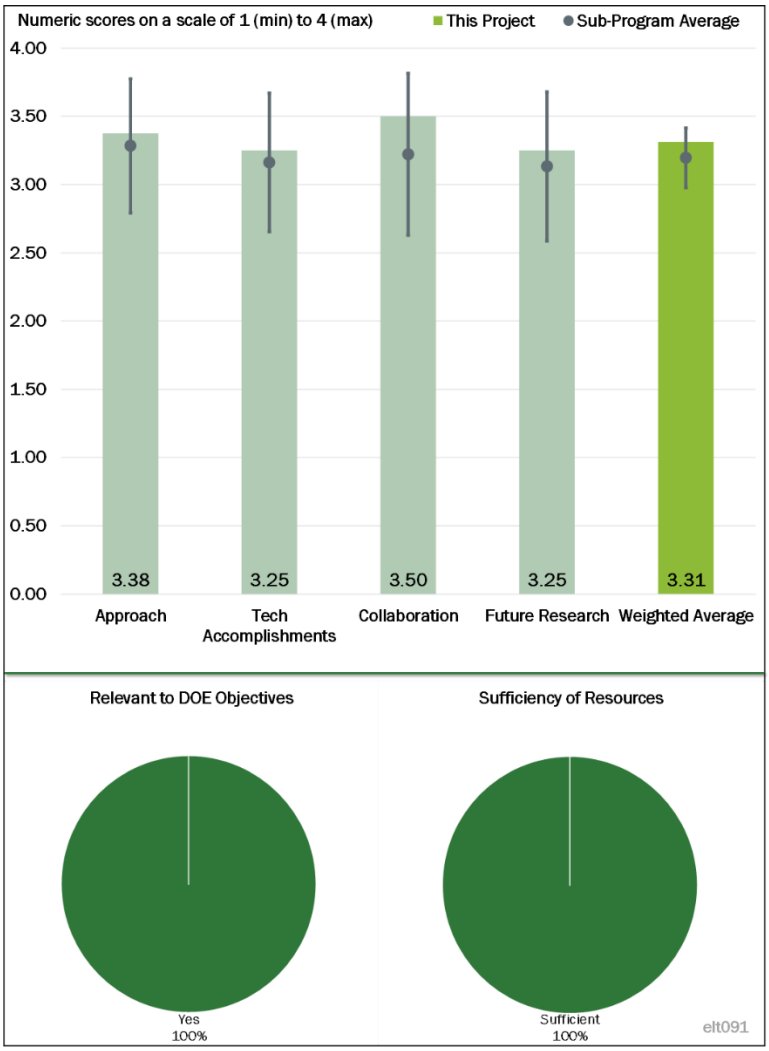

Figure 4-3 – Presentation Number: elt091 Presentation Title: Cost-Effective 6.5% Silicon Steel Laminate for Electric Machines Principal Investigator: Jun Cui (Iowa State University)

Reviewer 4:
The reviewer remarked the approach is good, but there are still significant challenges in terms of scalability especially for the 6.5% silicon (Si) laminations. The reviewer was not clear that these materials can come close to meeting the new DOE targets.

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

Reviewer 1:
The reviewer said the project well accomplished stated objectives.

Reviewer 2:
The reviewer said the project appears to have made progress towards the project objectives in the three key areas of magnet development, Si steel development, and motor development. The reviewer noted the phase 2 motor build appears to use existing commercially available materials, but the phase 3 build appears to focus on

refining the design to use the magnet and steel materials developed as part of the project, which is still to be performed.

Reviewer 3:
The reviewer remarked the progress is overall good, but comprehensive evaluations, such as efficiency and power density, is needed for electric machines that use this new material.

Reviewer 4:
The reviewer noted good progress, but even though the title of the project focuses on the 6.5% Si, more progress has been made on the permanent magnet.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer pointed out that the project has engaged a wide supplier base, which is very relevant.

Reviewer 2:
The reviewer said that the project appears to include close collaboration with other institutions, and the work is well-coordinated. The roles of the team members are clearly highlighted.

Reviewer 3:
The reviewer commented good collaboration between various entities, especially in terms of evaluating the motor performance with the proposed materials.

Reviewer 4:
The reviewer remarked the collaboration is feasible.

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 appears to be ending soon, and the future work appears to focus on completing remaining tasks, such as the motor testing and scaling up the material processes. The remaining work appears to be significant for the remaining time available for the project.

Reviewer 2:
The reviewer noted well-defined future goals.

Reviewer 3:
The reviewer said reasonable proposed work with focus on scalability.

Reviewer 4:
The reviewer was not very clear about future plans.

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

Reviewer 1:
The reviewer said this project does appear to support the DOE objectives in that it is focused on new materials to improve motor performance.

Reviewer 2:
The reviewer said yes, non-rare-earth motors are very relevant.

Reviewer 3:
The reviewer said it is relevant to DOE's goal to reduce the need of rare-earth materials.

Reviewer 4:
The reviewer remarked relevant to efficiency targets but not so much to power density targets.

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

Reviewer 1:
The reviewer said resources appear to be sufficient to accomplish the work and achieve the milestones.

Reviewer 2:
The reviewer remarked based on the proposed scope, resources seem sufficient.

Reviewer 3:
The reviewer said resources seem to be sufficient to complete the project objectives.

Reviewer 4:
The reviewer commented that the project has adequate resources.

Presentation Number: elt092
Presentation Title: Wound Field and Hybrid Synchronous Machines for Electric Vehicle Traction with Brushless Capacitive Rotor Field Excitation
Principal Investigator: Ian Brown (Illinois Institute of Technology)

Presenter
Ian Brown, Illinois Institute of Technology

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 and well-planned.

Reviewer 1:
The reviewer remarked that the team has been able to design an excellent power coupler with high efficiency. The hybrid excitation looks very promising at this point. The reviewer said it will be very good if the team can compare the final prototype against U.S. DRIVE 2025 targets. The reviewer noted that collaboration and coordination between the groups seem to be excellent, and proposed future research will address the remaining technical barriers.

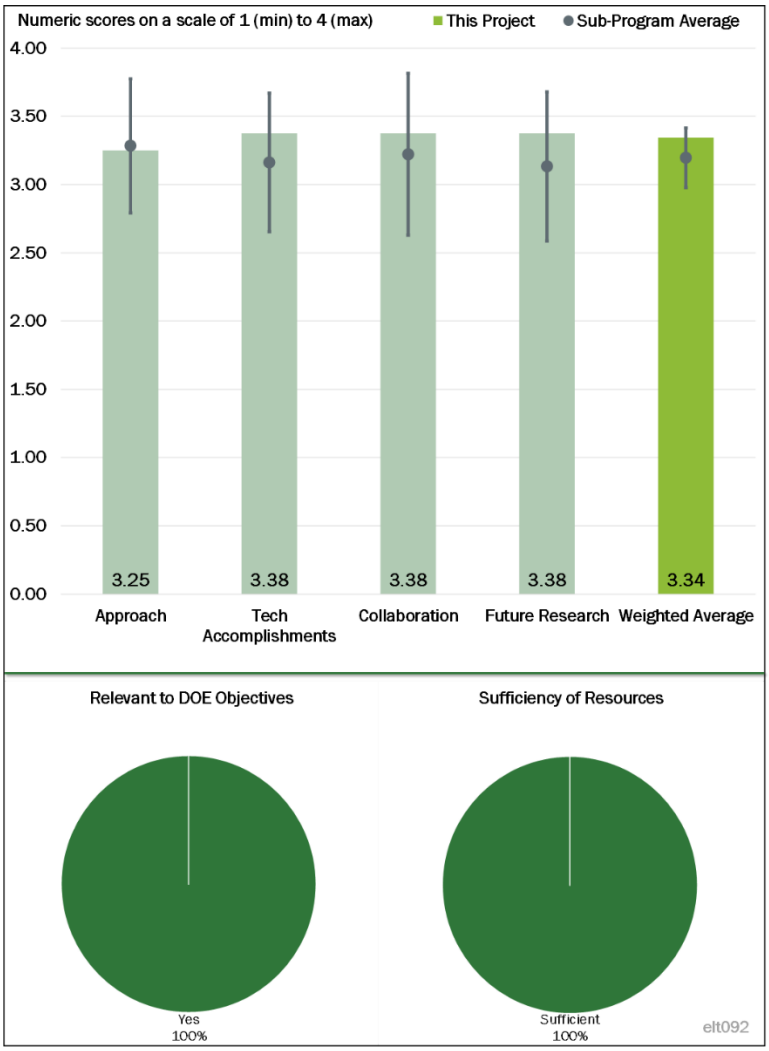

Figure 4-4 – Presentation Number: elt092 Presentation Title: Wound Field and Hybrid Synchronous Machines for Electric Vehicle Traction with Brushless Capacitive Rotor Field Excitation Principal Investigator: Ian Brown (Illinois Institute of Technology)

Reviewer 2:
The reviewer commented the approach of the project is focused on several key items, including die compressed windings, low scrap designs, machine optimization, and controls development. This covers a range of topic areas to investigate multiple paths towards improving the cost electric machines for electric drive applications.

Reviewer 3:
The reviewer said the approach is feasible.

Reviewer 4:
The reviewer remarked there are so many things that have been tried and it is somehow difficult to quantify the impact of each of them. The reviewer pointed out that the test results of the down-selected prototype will be helpful in that regard.

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

Reviewer 1:
The reviewer said that overall, progress has been excellent. Impressive knowledge dissemination through publications. The reviewer said it seems that the project team is on track to finish on time.

Reviewer 2:
The reviewer said the project is progressing smoothly.

Reviewer 3:
The reviewer noted that the project appears to have several technical accomplishments for each of the listed focus areas of the project. The project listed a predicted volumetric power density of 42.68 kW/L, which is close to the 2025 targets. It will be interesting to see the prototype performance. The reviewer said the slides also highlight the motor continuous power is not limited by cooling. The reviewer pointed out that more information about the thermal limits of the motor would be helpful in understanding the thermal limitations and how the motor is cooled.

Reviewer 4:
The reviewer said there is good progress being made, but the reviewer also had some concerns. First, it is not clear what the additional benefit is of the die pressing of the windings, especially that the down-selected prototype has segmented stator structure. Second, the pressure levels used are too high and might compromise the wire insulation. Some sort of accelerated life testing is needed. Third, the masses and volumes used seem to be based on active quantities. This needs to be adjusted to "total" quantities for a fair comparison.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer remarked the project appears to include close collaboration with other institutions and the work is well-coordinated.

Reviewer 2:
There is good collaboration, especially between the Illinois Institute of Technology and University of Wisconsin-Madison.

Reviewer 3:
The reviewer said the collaboration looks reasonable.

Reviewer 4:
The reviewer said the team has coordinated very well, and would expect more participation from Lucid Motors.

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 the future plan is reasonable.

Reviewer 2:
The reviewer remarked the proposed plan seems to address the remaining questions and barriers. The reviewer will be extremely curious to look at the final test results of the full power dynamometer testing.

Reviewer 3:
The reviewer pointed out that the project appears to be ending soon, and the future work appears to focus on a range of items, including completing the high-power motor testing. Future work also lists a detailed cost evaluation, which would be helpful to compare the overall electric drive costs.

Reviewer 4:
The reviewer noted that building and testing a prototype is a critical step to prove the analysis.

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

Reviewer 1:
The reviewer said that this project is addressing a critical focus of DOE, which is finding an alternative to rare-earth PM-based traction motors without sacrificing torque density. So far the project has produced exciting results.

Reviewer 2:
The reviewer noted that an increase of the power density is relevant to DOE's goals.

Reviewer 3:
The reviewer remarked this project does appear to support the DOE objectives in that it is focused on improving the power density and cost of electric motors.

Reviewer 4:
The reviewer remarked some aspects are relevant, but a fair comparison to a baseline IPM is needed. Also, testing the prototype will help confirm the analysis results as well as show any unforeseen issues

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 the available remaining resources are commensurate to the remaining time and project milestone.

Reviewer 2:
The reviewer remarked resources appear to be sufficient to accomplish the work and achieve the milestones.

Reviewer 3:
The reviewer said based on the proposed scope, resources seem sufficient.

Reviewer 4:
The reviewer commented yes, the resources are sufficient.

Presentation Number: elt093
Presentation Title: High-Speed Hybrid Reluctance Motor with Anisotropic Materials
Principal Investigator: Edwin Chang (General Motors)

Presenter
Edwin Chang, General Motors

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 and well-planned.

Reviewer 1:
The reviewer commented the design of three motor variants with no heavy rare-earth (HRE) content is important.

Reviewer 2:
The reviewer said the approach of the project is focused on matching machine configurations with material technologies that are aligned with specific vehicle target applications. The work highlights that the relevance of different motor configurations depends on the targeted vehicle application.

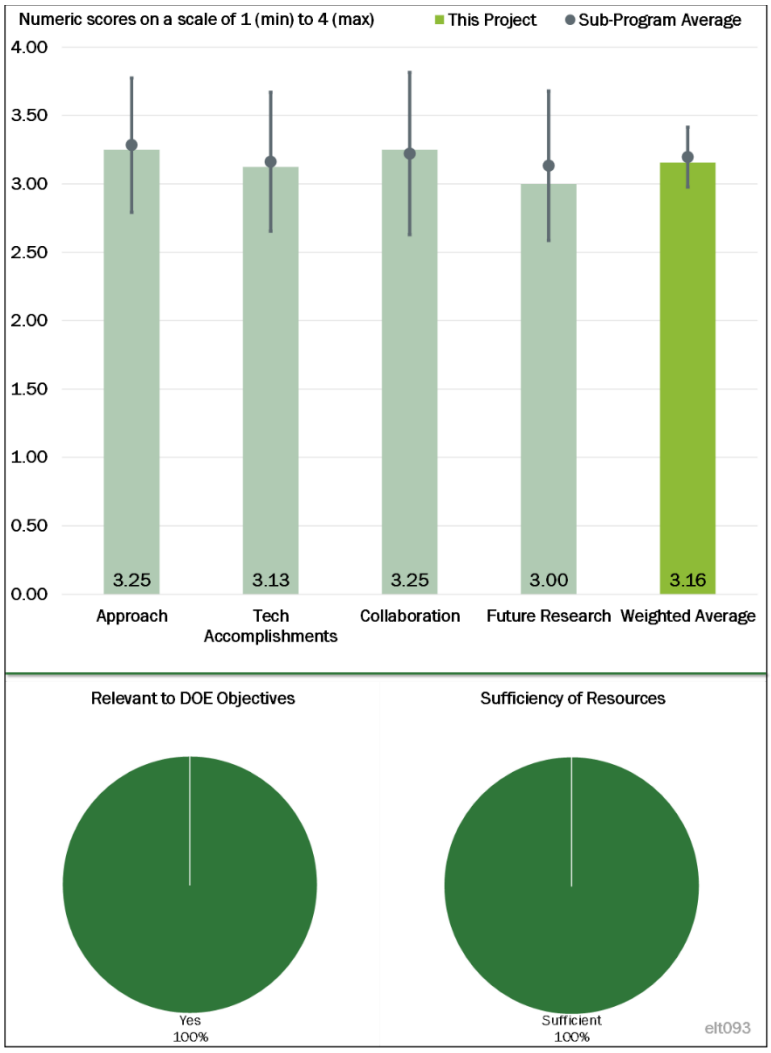

Figure 4-5 – Presentation Number: elt093 Presentation Title: High-Speed Hybrid Reluctance Motor with Anisotropic Materials Principal Investigator: Edwin Chang (General Motors)

Reviewer 3:
The reviewer commented the approach to performing the work has been good. However, the three motor variants designed have different mass, different volume, and a different power (as presented in Slide 25). This makes it extremely difficult to compare the three designs. The reviewer remarked a better approach could have been to fix one and look for others to vary.

Reviewer 4:
The reviewer pointed out that the key challenge is the novelty of the proposed topologies is limited and most of them have been extensively studied in literature.

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

Reviewer 1:
The reviewer said the project summarizes three potential motor designs and provides a nice and clear summary of the performance comparison. The project highlights the motor variations that do not meet the cost targets, and also includes a pie chart showing a rough comparison of the relative costs within the motor. The reviewer

said it would be interesting to know the key cost barriers that prevented the machines from not meeting the cost targets.

Reviewer 2:
The reviewer commented the project is progressing smoothly.

Reviewer 3:
The reviewer said there is good progress but test results are needed. Also, the masses and volumes reported seem to be based on active material and this needs to be adjusted to total material. The reviewer pointed out that the three proposed topologies are designed for different specifications, which makes the comparison more challenging.

Reviewer 4:
The reviewer said the progress has been good so far. The reviewer thinks there are so many numbers floating around in this project for comparison, the team is requested to clearly articulate the accomplishments. The summary/conclusion is yet to be distilled so that DOE/relevant researchers can understand the key outcome of this project.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted that comprehensive material testing and analysis has been performed by the partner institution. The reviewer believed the main institution could have benefited more by tapping into the reach expertise available with the partner institution in terms of machine design and comparison.

Reviewer 2:
The reviewer said good collaboration with various entities.

Reviewer 3:
The reviewer said the project appears to include close collaboration with other institutions and the work is well coordinated.

Reviewer 4:
The reviewer said the collaboration is feasible.

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 appears to be ending soon, and the future work appears to focus on testing the motors to confirm the analytical results.

Reviewer 2:
The reviewer remarked that test results (including burst test and life testing) will be critical to verify the analysis results.

Reviewer 3:
The reviewer said that the proposed future research is good. The reviewer requested that the team please compare the three variants effectively and distill the information needed to convince the key stakeholders about the best design out of the three.

Reviewer 4:
The reviewer asked can the project team compare this machine with other rare-earth-free machines such as switched reluctance machines.

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

Reviewer 1:
The reviewer remarked this project does appear to support the DOE objectives in that it is focused on improving the power density and cost of electric motors.

Reviewer 2:
The reviewer stated yes; it is relevant to DOE's goal of reducing the need for rare-earth materials.

Reviewer 3:
The reviewer indicated that the program objective supports overall DOE goals by investigating options for HRE-free magnets designs.

Reviewer 4:
The reviewer commented some aspects are relevant but the novelty is not significant.

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 resources are sufficient.

Reviewer 2:
The reviewer said resources are sufficient.

Reviewer 3:
The reviewer remarked resources appear to be sufficient to accomplish the work and achieve the milestones.

Reviewer 4:
The reviewer commented based on the proposed scope, resources are sufficient

Presentation Number: elt094
Presentation Title: Development and Demonstration of Medium- and Heavy-Duty Plug-In Hybrid Work Trucks
Principal Investigator: John Petras (Odyne Systems)

Presenter
John Petras, Odyne 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 and well-planned.

Reviewer 1:
The reviewer observed a good technical breakdown of the system, and identification of specific requirements for each of the components.

Reviewer 2:
The reviewer pointed out that the workflow for this project is well structured, with technical barriers and go/no-go decision points clearly specified in the statement of work. The project is currently slightly behind schedule with respect to the original timeline, but in the presentation it was not clear whether this would constitute a problem or carry a risk of further delaying the deployment and demonstration phase.

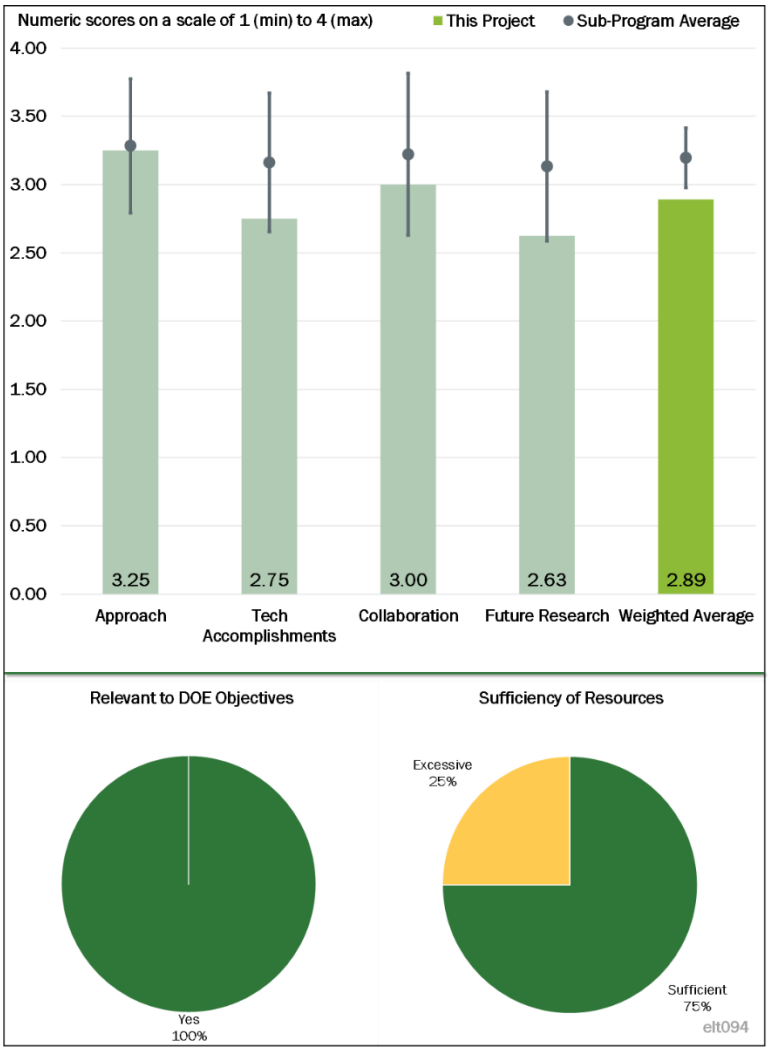

Figure 4-6 – Presentation Number: elt094 Presentation Title: Development and Demonstration of Medium- and Heavy-Duty Plug-In Hybrid Work Trucks Principal Investigator: John Petras (Odyne Systems)

Reviewer 3:
The reviewer observed the objective of this project is to develop and demonstrate an advanced plug-in hybrid electric vehicle (PHEV) medium-duty work truck with greater than 50% reduction in fuel consumption when compared to a conventional diesel vehicle baseline. The project has three phases including, first, system design and analysis; second, prototype build, refinement, and verification; and third, vehicle customer deployment and demonstration. There are three primary focus areas including optimizing the powertrain and full vehicle energy use; battery system sourcing and development; and chassis, vehicle, and system development and integration. The reviewer noted that barriers identified include fuel efficiency of medium-/heavy-duty work trucks, integration of driving and jobsite electrification, and the fact that over 50% of work truck fuel use occurs during stationary operation—which is not typically addressed by traditional hybrid solutions. The reviewer remarked this project is directly focused on and well situated to largely overcome these barriers.

The reviewer stipulated that work trucks are unique in the proportion of fuel used during stationary activity and the diversity of vehicle design and jobsite equipment utilized to fulfill their missions. An excellent attribute of

this project is that it is pursuing a modular PHEV work truck solution which meets the needs of this variety of work truck users while still demonstrating a 50% reduction in full-day fuel use. The reviewer remarked this design proposed by this project is flexible being modular and applied to multiple OEM chassis and application platforms using the same base hybrid system. It is minimally intrusive providing hybrid power through the existing power take-off (PTO) port connection with the transmission with no changes to the base powertrain while maintaining the Allison powertrain warranty. The reviewer noted that this design supports all field functions, exhibits equal or improved performance, and allows field recharge via the diesel engine, if required, with no interruption in jobsite function. Overall, this project is very well designed and completely feasible.

Reviewer 4:

The reviewer remarked the approach to aspects such as packaging, selecting the most optimum components, reducing weight, and so forth were excellent, but the goals/objectives were too broad and nebulous for this particular project. A goal of 50% fuel consumption compared to conventional diesel vehicle baseline is insufficient—the conditions were not specified, such as under what duty cycle, what type of PTO (bucket truck, mobile crane truck, air compressor [jack hammer] truck, or electric generation truck), and what ratio of driving to PTO.

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

Reviewer 1:

The reviewer said the project team is overcoming significant challenges in the sourcing of components and integration on the truck. While accomplishments have been achieved in different areas of the project, it is currently not very clear how those achievements can contribute to achieving the 50% fuel economy improvement objective.

The reviewer noted that preliminary fuel economy improvement estimates have been provided, but only in simulation. While the results point towards 51% in fuel economy improvement (target is 50%), the margin of error of the models should be accounted for. In other words, fuel economy improvements could result much lower in vehicle testing phase. The reviewer was also unclear how the numbers were generated (for which type of driving/work profiles).

Reviewer 2:

The reviewer said there is room to improve on high voltage battery selection relative to weight and cost. Specifically regarding weight, fuel reduction benefits in service mode should not be jeopardized for by additional vehicle weight thus decreasing driving fuel efficiency.

Reviewer 3:

The reviewer said the project has demonstrated significant technical accomplishments and progress in each of its focus areas.

Regarding Powertrain and Full Vehicle Energy Use, the reviewer said that the subsystem and component selection has been completed and design integration into Freightliner M2 chassis has been completed. The powertrain has been selected with a more compact motor design, more easily accommodated envelopes, and significantly easier installation. The reviewer noted that power electronics integration has been achieved with improved performance, packaging, and ancillary savings (which help cost savings). Additionally, better performance than the baseline vehicle has been achieved. A/C has been integrated into the chassis eliminating specialty components (saving costs) and with significant assembly, service, and customer satisfaction improvements.

Regarding the Battery System, the reviewer noted that requirements and targets have been created around a 350 volt (V), 10-16 kWh base system. The team has conducted a supplier search, and over 50 OEM, Tier 1, and mid-level pack producers contacted. The reviewer pointed out that challenges exist in that most large

OEMs and Tier 1's are not interested due to low volume. Unfortunately, due to low volumes, available modules, and the difficulties of packaging a modular system, quoted battery prices are in the $800-$850/ kWh range. The reviewer noted that two battery systems (Torqeedo 11.5 kWh and Octillion 14.9 kWh) have been selected and are currently undergoing evaluation with a continuous power target of greater than 30 kW. The reviewer pointed out that a question arises due to the high cost of the batteries (which will need to be periodically replaced) and the need to achieve a competitive lifecycle return on investment. It is probably water over the dam now, but it may have been beneficial to have first scoped the specs (including costs) and availability of battery technologies and then used that information to inform the team's battery requirements (without compromising customer requirements). In this way, according to the reviewer, a system design may have been feasible that could incorporate widely available/cheaper battery technologies without being overly detrimental to vehicle performance. If this is possible, it may have a gone a long way to improving overall system return on investment (ROI) and marketability.

Regarding Powertrain Control, the reviewer noted that the National Renewable Energy Laboratory (NREL) has developed three specific work truck duty cycles for modelling and dynamometer testing based on 119 vehicle/15,000 days of telematics data. These duty cycles are full year and define key parameters for both driving and stationary work applications. NREL has conducted baseline dynamometer testing and Odyne/Oak Ridge National Laboratory (ORNL) have conducted PHEV model development and correlation to dynamometer data. The reviewer said that ORNL's simulation model was utilized to evaluate multiple iterations of refined driving strategies including increased speed range of torque assist, increasing peak torque, balance load, and idle neutral. The reviewer noted that results indicate 34%-51% fuel economy improvements over baseline diesel.

Regarding Moving Toward Testing, the reviewer said that hardware-in-the-loop (HIL) parts are in final procurement, and test chassis has been received and the hybrid build is 80% complete.

The reviewer concluded overall, an impressive list of accomplishments which have been achieved on schedule and budget.

Reviewer 4:

The reviewer found that the major technical accomplishments are excellent: First, Parker motor and Chelsea extended PTO; second, integrated charger, direct current (DC)/DC inverter and export power unit; and third, integration of the air conditioning with the chassis system eliminating secondary blower/evaporator and compressor. However, remarked the reviewer, there was no energy budget analysis to show how these particular technical accomplishments achieved either in theory or in testing incremental reductions in fuel consumption or progress towards the 50% reduction goal

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said the collaboration across team members is balanced and well integrated.

Reviewer 2:

The reviewer commented that the Odyne team has an extensive list of collaborators including National Laboratories (NREL and ORNL), industry (Freightliner, Allison, and Ricardo Strategic Sourcing), utility (Los Angeles Department of Power and Light), and South Coast Air Quality Management District (SCAQMD). The reviewer noted that their respective roles and responsibilities have been identified, and close collaboration appears evident.

Reviewer 3:

The reviewer noted there were slides enumerating the collaborators on the project team, but when it came to what the end-users did or how they collaborated with the rest of the project team, there was neither any information presented nor discussion of their participation. The reviewer pointed out that end-user

participation is crucial to success. It looked like the National Laboratories dominated the budget and theoretical effort.

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 baseline fuel consumption in driving mode based on conventional system shall be included in future research to compare with anticipated real-life fuel consumption of proposed hybrid architecture. Referencing Slide 30, the reviewer noted that analysis for the additional vehicle miles traveled (VMT) with electrified powertrain, if any, is related to additional trips necessary to reach charging station for vehicle charging.

Reviewer 2:
The reviewer remarked future tasks have been explained clearly. It would be worth specifying the estimated timeline, particularly as the project appears to be slightly delayed with respect to the original scheduling. The reviewer noted it is likely that the results obtained (fuel economy evaluation) will be limited to a specific area of application (e.g., bucket trucks for electrical service). It would be worth providing simulation or test results (perhaps by leveraging deployment efforts with other customers, beyond the partners directly involved in this project) to evaluate the opportunity for fuel economy improvement in other application areas, to better understand the impact of the technology.

Reviewer 3:
The reviewer detailed that proposed future work will include refining driving improvements on system simulation and HIL development, evaluating remaining battery options and selecting a final solution, and developing a simple strategy to address full-year duty cycle and how to best balance a modular system between stationary and driving activities considering system cost. The reviewer said the project will also proceed with prototype build, refinement, and verification. This includes installing a fully functional hybrid/diesel powertrain at ORNL, completing prototype build and verifying functionality of the prototype test unit, incorporating full day optimization, and building and deploying a demonstration and evaluation fleet of 10 vehicles. In the next period, analytical demonstration of 50% reduction in work truck fuel use will be shown.

The reviewer asked if the project is going to develop one control strategy best optimized for on-road and stationary fuel use for a combination of work truck applications. In other words, one optimized control strategy for all applications, or would it be potentially beneficial to develop and implement several control strategies tailored to specific driving and stationary work applications.

The reviewer asked given the criticality of achieving a competitive ROI for consumer marketability, are there any other cost savings measures not previously mentioned that Odyne is (or should) be considering.

Reviewer 4:
What is very troubling to this reviewer is the design of the algorithm for optimizing driving. It is not clear how this algorithm will be used because there was no option for the driving cycle to be predicted or to be chosen before the vehicle is started for the day. Second, too much emphasis was placed on the driving cycle and hardly any consideration given to the power requirements and cycling of power during the PTO when the vehicle is stationary. The reviewer said it is not even clear how energy is stored from regeneration during driving—is this enough to supply all the energy needed for PTO. The reviewer said some kind of energy balance analysis is needed and was not conducted.

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

Reviewer 1:
The reviewer remarked this project is relevant because it makes an earnest attempt to reduce power consumption.

Reviewer 2:
The reviewer said contributing to the overall goal of reducing energy consumption through the project's target to decrease of fuel consumption up to 40% for specific application.

Reviewer 3:
The reviewer said the project supports the overall DOE objectives by providing an add-on package to improve fuel economy of work trucks. While the market is small, there are unique challenges (extreme diversification of applications and customization) to this market that need to be addressed.

Reviewer 4:
The reviewer commented this project is relevant and supports VTO and DOE objectives to reduce transportation fuel use by developing a marketable, modular work truck option that meet user needs while demonstrating a 50% reduction in full-day fuel use.

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 allocated for the project are sufficient and commensurate to the objectives to be reached.

Reviewer 2:
The reviewer observed no evidence for missing or excessive resources.

Reviewer 3:
The reviewer detailed that this project is a 4-year, $7 million industry design, development, and demonstration effort that has a 31% ($2.149 million) DOE cost share. Industry is contributing 58% ($4.023 million) and the National Laboratories 11% ($783,000). The reviewer said the project is currently 50+% complete, has not met any demonstrable show stoppers, appears on schedule, and no mention has been made of future funding constraints. As such, the reviewer can assume that the allocated resources are sufficient to achieve the remaining milestones and bring the project to fruition.

Reviewer 4:
The reviewer commented that too much money is being spent at the National Laboratories, and not enough analysis was done upfront to empirically determine the energy balance between driving and PTO.

Presentation Number: elt095
Presentation Title: Vehicle-to-Grid Electric School Bus Commercialization Project
Principal Investigator: Dennis Whitaker (Blue Bird Corporation)

Presenter
Mike Boggess, Blue Bird Corporation

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 and well-planned.

Reviewer 1:
The reviewer commented the technical approach to the project was clearly explained and appears well articulated. The team developed an initial extensive list of potential areas for fuel economy improvement and prioritized a short list of objectives to achieve within a given time and effort. This is an excellent approach for a project focused on integration, deployment, and demonstration. The reviewer identified as a potential risk of this strategy is that only incremental improvements could be achieved, rather than exploring more "high-risk" solutions requiring a ground-up redesign of the vehicle or powertrain. The reviewer said this poses the risk of not meeting the aggressive fuel economy improvement targets.

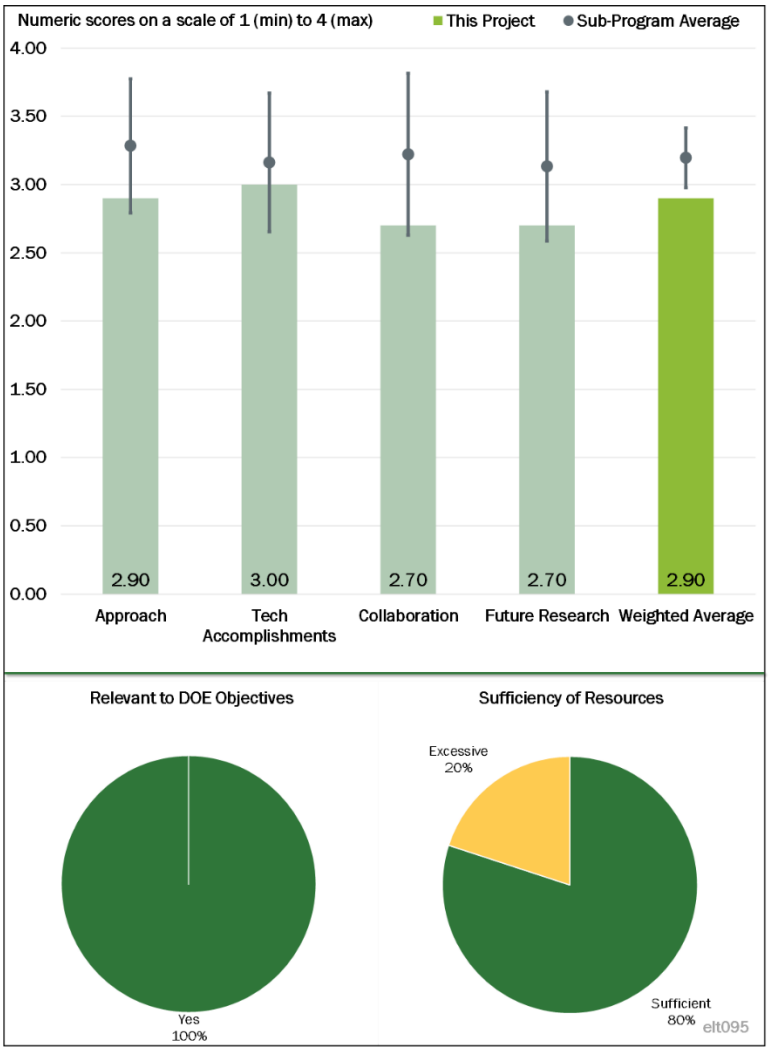

Figure 4-7 – Presentation Number: elt095 Presentation Title: Vehicle-to-Grid Electric School Bus Commercialization Project Principal Investigator: Dennis Whitaker (Blue Bird Corporation)

Reviewer 2:
The reviewer detailed the overall objective of this project is to create a compelling value proposition for electric school buses based on a competitive total cost of ownership. This includes equipping an electric school bus with vehicle to grid (V2G) and vehicle-to-bus (V2B) income generating grid integration capabilities and advancing the technical maturity of selected medium-duty electric components to achieve superior energy efficiency and reduce operating costs. A fundamental assumption underlying the project is that a competitive total-cost-of-ownership can be achieved for an electric school bus through optimization of three parameters including bus capital cost, bus operating cost, and revenue generated from grid integration. The reviewer noted a high level barrier identified includes cost/performance tradeoffs for heavy-duty EVs that have not yet been thoroughly mapped out. In addition, the design of high-power charging systems is lagging where components for high-power AC charging are only appearing slowly and the pathway to conform with existing and emerging standards is not well established.

The reviewer noted that Blue Bird is addressing these challenges, exploring potential technology improvements, and prioritizing those that deliver the best value. This provides an opportunity to revisit the conventions of school bus design and consider changes to meet the parameters of vehicle electrification. Blue Bird started with three technology improvement focuses: integrated thermal management, advanced telematics, and high-power charge/discharge capability and one broad category, "smart design." This led to a list of more than 100 improvement ideas, each being evaluated as function of efficiency improvement to required effort and cost effectiveness. Ultimately, according to the reviewer, the three top areas with the most opportunity were identified as traction energy budget, mass reduction (especially rotational mass), and friction reduction.

The project's approach appears very practical, being focused upon cost/benefit tradeoffs and intent for marketability and commercialization. However, in support of this approach, it would be beneficial if on-going system cost analyses were being conducted to gauge progress toward cost effectiveness and provide the reviewer with greater confidence that progress toward ultimate marketability and competitive ROI was being achieved. In order words, establishment and periodic evaluation of a series of cost metrics throughout the project lifecycle. Additionally, little mention is made of the energy storage component (batteries) which will play a critical role in the efficiency and cost effectiveness of the system. The reviewer found that overall though, the project is well designed and clearly feasible.

Reviewer 3:
The reviewer remarked the approach is less than acceptable because it is lacking a concurrent review of whether the components, subassemblies, assemblies, and integration are compliant with Federal and state requirements for safety certification. Especially important is whether the changes to increasing regeneration torque and implementing closed loop regeneration affect compliance with the Federal Motor Vehicle Safety Standards for stopping distance.

Reviewer 4:
The reviewer said the project goes into a general direction to electrify propulsion. The V2G contribution is questionable—the technology is still at its infancy.

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

Reviewer 1:
The reviewer said the objectives for the current evaluation period included achieving an energy efficiency of 1.32 kWh/mile or better for prototype bus P1 (halfway to the target efficiency of 1.1 kWh/mile), initiating the process of adapting the high-power inverter platform to on-vehicle deployment, and completing design of the charging interface and specification of essential components. The reviewer remarked this project has demonstrated a number of technical accomplishments and progress.

Regarding Thermal Management, the reviewer noted improved thermal management of batteries via a high-performance heating/cooling loop and enhanced insulation; reduced "on-time" for coolant pump, AC compressor, and fan for battery, motor, and power electronics; and reduced overall weight by 16kg. Regarding telematics, the reviewer noted experimentation and modeling indicate that real time adjustment of electric drive components yields limited benefits and it is better to focus upon smarter onboard feedback control of acceleration and deceleration.

For Charging System Design, the reviewer said a cost assessment and commercial interface availability led to the decision to reduce inverter power to 150kW and the team is on track with software development/DBC file for rapid power import/export.

Regarding Traction Energy Budget, the reviewer said increased regen torque when not touching either pedal (coasting torque) and implemented closed loop regen to ensure maximum regen is achieved in all loading

conditions. Blue Bird is currently implementing a two-stage pedal to achieve maximum regen torque without engaging friction brakes.

For Rotation Mass and Inertia Reduction, the reviewer said a number of selections have been made including foundation brakes, lightweight seats, reduction in wheel size and weight, lightweight springs, hollow construction driveshaft, and drag reduction devices.

Regarding friction reduction, the reviewer noted the team identified opportunities to reduce friction in all forms. The team completed evaluation of low-rolling resistance tires and bearings and aerodynamic improvements, with a low friction rear axle/differential being evaluated.

The reviewer noted that through these measures the project has attained the interim energy efficiency target of 1.32 kWh/mile through four areas: traction energy budget, rotational mass and inertia reduction, and friction reduction. Overall, a strong list of technical accomplishments and progress this period.

Reviewer 2:
The reviewer said the project well addresses technical barriers and contributes to general EV advancement.

Reviewer 3:
The reviewer remarked a DC bi-directional charging could offer the overall arching target of vehicle weight and packaging. It is not clear why the project is not utilizing the DC charging architecture approach defined in SAE J1722 and commercialized. The reviewer said an analysis relative to justifying the V2G implementation is lacking to demonstrate the overall benefits for the added cost of the system versus the ROI.

Reviewer 4:
The reviewer commented the project has achieved technical accomplishments in different areas, by working in parallel on different solutions for improving the vehicle system integration, weight, and powertrain system. On the other hand, it is unclear whether incremental improvements in many areas will achieve the target FE improvement goals once all are integrated.

Reviewer 5:
The reviewer remarked while the technical accomplishments (increase regeneration braking capacity, reduce wheel size, lighter weight, etc.) per se are excellent, the progress in achieving the goal was not demonstrated. The reviewer said there should have been an itemized energy analysis to show how each accomplishment contributed incrementally to the goal of achieving an energy efficiency of 1.32 kWh/mile (1/2 way mark) from the original baseline of 1.53 kWh/mile.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted a well selected team. The interaction of all stakeholders especially related to the California Independent System Operator (CAISO) is not evident.

Reviewer 2:
The reviewer remarked Blue Bird has assembled a strong project team, including vehicle subcontractors (Cummins Electrified Power and EPC Power), charging system partners (Nuvve and Southern California Edison [SCE]), school bus host (Rialto USD), SCAQMD, NREL, and National Strategies. It appears the team covers the entire project lifecycle from technology modelling, research, development, establishment of charging requirements, through to testing, demonstration, and deployment. The reviewer said there was no mention made though of specific collaboration/coordination mechanisms across team members.

Reviewer 3:
The reviewer commented the team is finding new suppliers, but collaboration is mostly self-contained.

Reviewer 4:
The reviewer remarked the coordination across team members was not well articulated in the presentation, in particular it was not clear what each team member is responsible for and how the overall interaction among team members is managed.

Reviewer 5:
The reviewer said numerous partners are listed (the reviewer hopes this is not just for the pretenses of a "good show") but there was neither any description nor discussion of the involvement of end-users (Rialto USD, and SCE). The reviewer asked if the end user got to evaluate or comment on the implications of each technological advance or change.

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 project addresses future needs.

Reviewer 2:
The reviewer said it is valuable to include bi-directional charging ROI analysis based on CAISO assumptions.

Reviewer 3:
The reviewer remarked the remaining challenges and barriers have been presented; however, more attention should be given to explaining or providing indications on how the team plans to address each challenge.

Reviewer 4:
The reviewer remarked not enough analysis and planning went in before this project started to think about the cost-benefits of bi-directional charging. While the merits of bi-directional charging are anecdotal, a cost-benefit analysis should have been done beforehand to determine if the return of energy to the grid balances energy taken out from the grid. The reviewer said, if not, then are the costs of bi-directional charging justified by the credits for return of electricity to the grid, and how much does the use cycle of the V2G electric school bus match the power consumption cycle of the electric grid. The reviewer asked, if not worthwhile, then can the components, subassemblies, and integration for bi-directional charging be dropped to save money on the total cost of ownership (TCO) of the electric school bus (i.e., make the bus one-way only charging). The reviewer said it is not too late to determine whether the project is worthwhile to be saved.

Reviewer 5:
The reviewer noted that remaining project challenges and barriers have been identified, including the requirement to achieve technology objectives (energy efficiency of 1.1 kWh/mile and packaging and certification of the 150kW bidirectional on-board inverter), implementing the charging system, demonstrating buses both as transportation assets and distributed energy resources, and commercialization. The reviewer noted that immediate proposed future research heavily focuses upon achieving the aforementioned technology objectives including maximizing energy recapture, minimizing energy consumed by auxiliaries, finalizing lightweighting measures, and preparing for go/no-go #3 (Milestone 8 in 2Q FY 2020). Additionally, for the high-power charging system, efforts are focused on profile control and fault characteristics of the on-board inverter, collaborating on interface component development, and preparing for go/no-go #2 (Milestone 6 in 1Q FY 2020). The reviewer said future research will target final selection and realization of the energy efficiency target of 1.1 kWH/mile and attainment of all applicable certifications for high-power bidirectional charging system.

The reviewer appreciated the project's focus on a cost/benefit framework and ultimate intent to market commercially even if not all technical and cost targets are achieved. It is good that the project is not strictly a

technology development effort but has a strong market focus, including a market transformation plan with a battery leasing component. The reviewer said it would be beneficial, however, if future efforts and disclosures provided more transparency with regards to the progress on the cost/ROI front. This includes not only projected technology development/implementation costs, but more substantiated detail on V2G and V2B revenue potential. The reviewer cited as an example, does the electric bus duty cycle really line up appropriately with grid service needs for V2G and distributed energy resources (DER) requirements and how does this impact potential grid service revenue. Currently, the reviewer is left with the sense that the project is intent to focus on costs, ROI, and marketability, but is not provided with any definitive data nor quantification to validate this assertion, nor that it is ultimately achievable.

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

Reviewer 1:
The reviewer commented yes, this project is relevant as it is addressing VTO's core objective to reduce the cost of PEVs, and VTO's specific R&D objective to understand the potential impacts of EV charging on the nation's electric grid—in both case through pioneering V2G technology in heavy-duty vehicles. Additionally, this project will support overall DOE objectives by advancing the marketability of electric school buses and potentially lead to reductions in transportation energy use.

Reviewer 2:
The reviewer said the project is in line of DOE objectives to evaluate V2G technology.

Reviewer 3:
The reviewer said the project does support the overall DOE objective in developing fuel economy improvement solutions for heavy-duty vehicle applications.

Reviewer 4:
The reviewer remarked yes, good support.

Reviewer 5:
The reviewer said energy efficiency improvements and potential peak-shaving.

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 this is a 4 1/2 year, $10 million 50/50 cost share project due for completion in August 2021. Based on the project scope, the progress to date, and no mention of any significant funding challenges, it can be assumed the funding resources are sufficient to meet future program milestones and bring it to successful conclusion.

Reviewer 2:
The reviewer said no evidence for missing or excessive resources.

Reviewer 3:
The reviewer said resources allocated for the project are sufficient to accomplish the objectives.

Reviewer 4:
The reviewer remarked the project is well on track with allocated resources

Reviewer 5:
The reviewer commented the project did not take advantage or share lessons learned from other projects, especially the packaging and component selections of invertors and batteries in the medium-duty PHEV work

truck in order to save money and effort. Also, it is not clear that bi-directional charging has any positive value—its costs are not justified.

Presentation Number: elt158
Presentation Title: Zero-Emission Cargo Transport II: San Pedro Bay Ports Hybrid & Fuel-Cell Electric Vehicle Project
Principal Investigator: Joseph Impullitti (South Coast Air Quality Management District)

Presenter
Joseph Impullitti, South Coast Air Quality Management District

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 and well-planned.

Reviewer 1:
The reviewer said this has been a real labor of love—a long project with the goal to deploy multiple technology trucks with startups and small firms as well as established ones with many other competing priorities. The reviewer said the approach is excellent and will prove to be strong as results begin to become available as the trucks being doing real work.

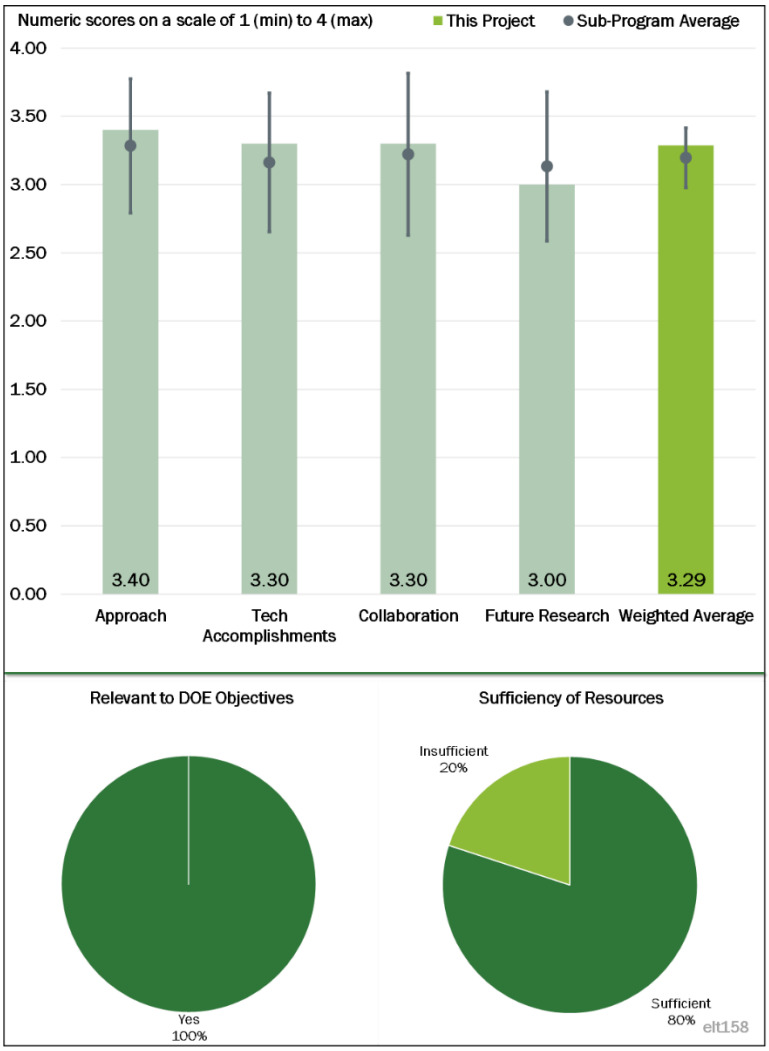

Figure 4-8 – Presentation Number: elt158 Presentation Title: Zero-Emission Cargo Transport II: San Pedro Bay Ports Hybrid & Fuel-Cell Electric Vehicle Project Principal Investigator: Joseph Impullitti (South Coast Air Quality Management District)

Reviewer 2:
The reviewer explained that the whole program is about addressing obstacles; it is a challenging project and getting all of the pieces working together is a major accomplishment.

Reviewer 3:
The reviewer said the project is near completion, most technical tasks have been completed in the allotted time and the plan for fulfilling the remaining tasks is clear.

Reviewer 4:
The reviewer said the overall approach to this project was to develop and deploy seven zero- or near-zero-emission cargo transport vehicles. The reviewer believed it was a good decision to partner with a variety of manufacturers/developers and integrators to develop the different trucks. The specific approach during the current review period was largely to complete the vehicle builds, perform shakedown testing/troubleshooting and to commission/deploy the vehicles into operation when ready. The reviewer found that this seems appropriate as the project nears completion.

Reviewer 5:
The reviewer said the barriers were mostly overcome (the fueling infrastructure in particular, at least in the short term), this reviewer finds that favorable. The reviewer's critique centers around the relative cost of the project with the short- and mid-term projections on feasibility not being favorable. Such future projects would be strengthened (or rejected) by upfront economic assessments of feasibility.

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

Reviewer 1:
The reviewer remarked getting all vehicles operational is a great accomplishment and the team is just about there. Good work.

Reviewer 2:
The reviewer remarked the project is nearing completion, the data collected from the deployment programs indicate that the program is on track to meet the technical goals. However, more time will be needed to collect and process the data from the different demonstrations. The reviewer inquired if the team can continue to collect the data (for potentially 3-4 years) with a no-cost extension.

Reviewer 3:
The reviewer pointed out that the project delivered six of the seven vehicles operational for use, testing, and data collection.

Reviewer 4:
The reviewer remarked during the current review period the technical accomplishments appear to have included setting up hydrogen fueling access for the trucks via portable hydrogen fueling stations, completing or nearly completing the building/integration of most of the trucks, and conducting or completing verification testing for several trucks. In one instance (for the TransPower Fuel Cell Truck #1), the vehicle was apparently prematurely deployed to Total Transportation Services, Inc. (TTSI) in 2018 before demonstrating adequate robustness and reliability verification testing. Hopefully, the current robustness and reliability verification testing for all of the vehicles are being performed to a higher degree of rigor. The reviewer said as the vehicles become ready for deployment, it would be good to see more standardized testing across vehicles to enable more direct performance comparisons between them (e.g., with consistent vehicle loads and duty cycles). The reviewer remarked it would also be good to have at least several months of data collection (if not indefinite as long as the vehicles remain in operation) to get a good picture of their in-use performance and to compare this against the performance of comparable conventional trucks.

Reviewer 5:
The reviewer indicated that the project team has been slogging along, year after year, building those trucks. Although this reviewer described progress as one step at a time—two forwards, one back—the team has been persistent and the end is in sight.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that collaboration among teams is very effective.

Reviewer 2:
The reviewer commented the project exhibited appropriate level of collaboration and coordination between the operators, manufacturers, and support.

Reviewer 3:
A major project accomplishment observed by this reviewer was finding and coordinating partners. The reviewer expected that this combination of technologies will not be significantly profitable, which speaks to the project team's collaboration skills in obtaining industry participation.

Reviewer 4:
The reviewer remarked excellent cooperation with the truck builders and component manufacturers to make this happen, also with the fleet. The reviewer believed some evidence of other collaborations, particularly with those who will help in the reporting of delivery metrics, etc., would help take the learnings to great.

Reviewer 5:
The reviewer said that collaboration seems good; as previously stated, it is good to have multiple manufacturers/developers and integrators involved. The one potential improvement area the reviewer identified would be better coordination for consistency in pre-commissioning testing of the trucks. It would also be desirable (perhaps as part of the future work plan) to get manufacturer input on the expected production costs for these trucks based on today (if they were to be scaled up to comparable production volumes as conventional cargo transport truck production), in addition to any anticipated pathways to bringing these costs down.

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 objectives outlined for the remaining challenges and future work are consistent with the objective of the project. The reviewer remarked it would be useful to establish a timeline and roadmap for the remaining tasks. Whereas the scope of the project is mainly deployment and data collection, it is unclear whether there is a long-term plan beyond this initial demonstration.

Reviewer 2:
The reviewer commented the description of future work is promising, but rather vague. Acknowledging possible impatience to see the answers, this reviewer further remarked that establishing a commercialization roadmap for a technology that will be very expensive is going to be a major challenge.

Reviewer 3:
The reviewer noted that the immediate future work plans appear to include completing vehicle builds, verification testing and troubleshooting of any issues, then deploying the trucks, collecting data, and making comparisons to present day conventional trucks. Each of these activities seems appropriate. The reviewer said the presentation indicated that a cost of ownership analysis would be conducted considering fuel and maintenance costs. The reviewer recommended that capital costs also be considered as part of this analysis (this could take the approach of assessing what the capital costs are today for these zero-/near-zero-emission trucks, what they would need to be to show overall equivalent cost of ownership and operation with present day conventional trucks, or some combination that would enable an assessment of the benefits provided by these trucks relative to their incremental costs). Along these lines, the presenter mentioned plans to establish a "roadmap for commercialization." Within such a roadmap, it could be reasonable to see some level of perpetual cost increment between these zero- and near-zero-emission vehicles and comparable conventional alternatives given the fuel diversification, energy security, and emissions benefits of the new technologies, but the roadmapping exercise should at least seek to understand what that cost increment is today and what it could be in the future. The reviewer said it was promising to hear the presenter comment that other manufacturers are looking at producing zero- and near-zero-emission freight vehicles (listing in addition to Kenworth both

Toyota and Daimler), such as under the auspices of the Zero-Emission and Near Zero-Emission Freight Facilities (ZANZEFF) program.

Reviewer 4:
The reviewer and the rest of the industry is very excited to now get reports on the performance of these trucks; uptime, fuel use, driver satisfaction, etc. But there was little evidence that there is the budget for time and money. When asked by a reviewer, the answer was that the team hopes we have funding to do a proper evaluation. The reviewer sure hopes we can find the means to or the success of this program will be greatly diminished. The reviewer hopes to see results either in the 2020 VTO Annual Merit Review (AMR) or by other means.

Reviewer 5:
The reviewer said that future work is centered around evaluating the potential market, cost, and economic analysis of the technology approaches. This is critical work; however, this reviewer believes this should have been done to some extent up front prior to building and demonstrating the technologies. Up-front economic analysis could yield results that would not allow a project to go forward due to cost feasibility and should be the starting point for projects similar as this.

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

Reviewer 1:
The reviewer said the project is very relevant to understand where battery technology will end and hydrogen will be required.

Reviewer 2:
The reviewer said that the project supports DOE objectives by deploying and demonstrating a heavy-duty fleet of fuel-cell, zero emission vehicles.

Reviewer 3:
The reviewer explained that if DOE is going to ensure energy security, it needs to have good information on what technologies are available, at what cost, what works, and what is too expensive. This project will certainly contribute to that knowledge base.

Reviewer 4:
The reviewer remarked prototype zero-emission cargo transport vehicle development and demonstration is relevant to improving energy efficiency, fuel diversity/resilience, and local air quality around ports. The reviewer noted that the presentation identified relevant barriers and challenges as including fueling infrastructure (which is being addressed via temporary portable hydrogen stations and through the separate ZANZEFF project), system integration (which is being addressed via the overall vehicle development and deployment activities under this project), and costs (which the presentation/project does not seem to be addressing).

Reviewer 5:
The reviewer said yes, and remarked the integration and demonstration of alternative energy sources supports the DOE mission of reducing petroleum use and supporting advanced technologies in the transportation marketplace.

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 this is a relatively expensive project; however, the vehicles were developed and demonstrated. It is commendable that all of these different platforms were developed and are being demonstrated.

Reviewer 2:
The reviewer found that resources are sufficient.

Reviewer 3:
As far as this reviewer could tell the resources seem sufficient. It also sounded like sufficient resources remain to implement a no-cost time extension to the project so that data collection can occur past the end of the current fiscal year as the remaining trucks get deployed (which would be good).

Reviewer 4:
It was no surprise to this reviewer that building these trucks was expensive. Citing no opportunity provided to comment on the information presented, there would have been no way to understand the architecture of the truck systems had this reviewer had not previously evaluated this project. Just a simple statement that these were electric trucks and the fuel cell was added as a range extender would have helped. The reviewer emphatically expressed being mystified that all that was said about the batteries was that they are X kWh Li-ion. The reviewer requested information on how the range-extended trucks would compare to straight electric, how much range was added, and at what cost. It would help to put the trucks in perspective and note the likelihood of interest outside California.

Reviewer 5:
The reviewer said that no evidence was presented to prove that the evaluation planned with this project will actually happen.

Presentation Number: elt187
Presentation Title: Comprehensive Assessment of On- and Off-Board, Vehicle-to-Grid Technology Performance and Impacts on Batteries and the Grid
Principal Investigator: Sunil Chhaya (Electric Power Research Institute)

Presenter
Sunil Chhaya, Electric Power Research Institute

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 and well-planned.

Reviewer 1:
The reviewer remarked this is an exciting project. Transformer monitoring and control for on-vehicle alternating current (AC) V2G and smart power integrated node (SPIN) for off-vehicle DC V2G are both are exciting parts. The reviewer noted that so far the team has provided excellent results. The test equipment at the National Transportation Research Center (NTRC) and the SPIN is impressive.

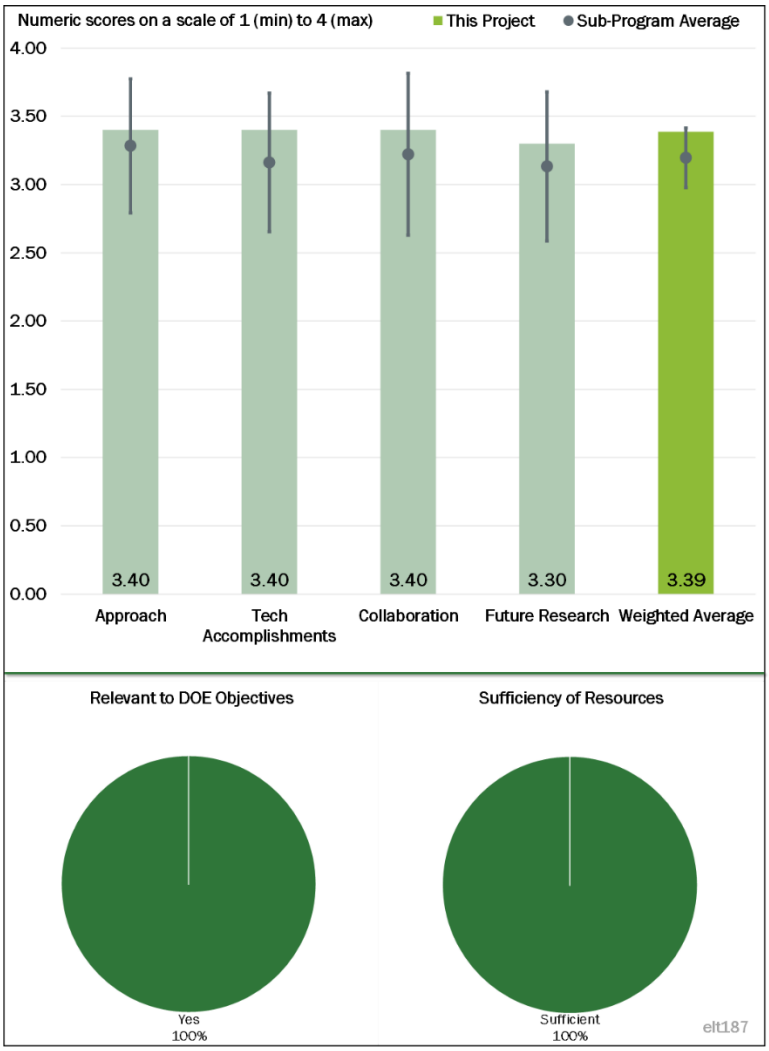

Figure 4-9 – Presentation Number: elt187 Presentation Title: Comprehensive Assessment of On- and Off-Board, Vehicle-to-Grid Technology Performance and Impacts on Batteries and the Grid Principal Investigator: Sunil Chhaya (Electric Power Research Institute)

Reviewer 2:
The reviewer said that the project is on track and 75% complete. The partner group is sufficient and the barriers addressed.

Reviewer 3:
The reviewer said there is a somewhat complicated project structure, but that appears to be due to having a lot of activities included under this project. The team does seem to have a rational approach for getting through all these elements, though the complexity may have something to do with the schedule delays. The reviewer noted that this is an important project to answer critical questions, many at the same time the industry standards are evolving, so the team is shooting at a bit of a moving target. The team seems to have structured their project to address this situation, and therefore have been adjusting some activities along the way.

Reviewer 4:
The reviewer commented that the proposed two standards-based architectures for V2G, which take both on-vehicle AC V2G and off-vehicle DC V2G into consideration, appear to be a good approach to address the barriers of on- and off-vehicle hardware (such as the bi-directional converters, and SPIN, etc.), and standards implementation.

Reviewer 5:
The reviewer said the projects aims to demonstrate power electronics and energy management controls that integrate bi-directional power flow from vehicle to grid, considering the impact of renewable energy and stationary energy storage for on-vehicle (AC) and off-vehicle (DC) charging systems. The reviewer pointed out that the project has been extended from original end date of 11/2019. Based on the Milestones presented, Phase 3 of the project has recently started and is estimated to be completed in one year. In the reviewer's opinion, the proposed timeline for budget period 3 is extremely aggressive, particularly considering the presence of significant verification, data collection, and post processing.

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

Reviewer 1:
The reviewer remarked the team has effectively reduced most of the technical barriers. Some of the key accomplishment includes a V2G value benefit assessment estimates of $407/EV/year, and completed the transition of SPIN to an ORNL lab. The progress is great.

Reviewer 2:
The reviewer commented that the project is on track. The on-vehicle V2G demonstration has been completed, and the off-vehicle V2G/DER integration is in progress.

Reviewer 3:
The reviewer remarked the results are shared and the project is 75% complete, results suggest the project may be completed by the end date of 2020.

Reviewer 4:
The reviewer said the team does seem to be making progress on important issues, though they are somewhat behind. A particular challenge for this project is that many of the related standards are also evolving at the same time.

Reviewer 5:
The presentation outlines the accomplishments achieved to date (Slide 7); however, it does not clearly match the milestones specified for budget period 2 in Slide 6.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that, clearly, the team has a collaboration and coordination plan, which is working great.

Reviewer 2:
The PIs have a very good team assembled, including technology/vehicle providers and two National Laboratories, pretty much exactly who you would want to see them include. Because the project is led by EPRI, the expectation is that the results should have successful dissemination to the utility industry.

Reviewer 3:
The reviewer observed a good mix of partnering with National Laboratories (i.e., NREL) and industry (Fiat Chrysler Automobiles [FCA]), as well as power electronic partners.

Reviewer 4:
The reviewer observed that the team members are from National Laboratories, an OEM, suppliers and firms, and each team has carried out different tasks of the project, which indicates an effective collaboration.

Reviewer 5:
The reviewer remarked the project team is very large, including three large Industry partners and two major National Laboratories. The reviewer is concerned that managing such a large team could produce further delays 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 that the proposed future research seems promising. Understanding of impact to vehicle battery durability and cycle is the most important aspect, in this reviewer's opinion.

Reviewer 2:
The reviewer said the team does have a clear plan in place for future research, both under this project and after. The team correctly acknowledges that not all challenges/barriers identified will be addressed under this project. Particular attention is warranted for the battery durability testing that the team will be doing under this project, where the tasking has been reconfigured. The reviewer said that under these efforts, the team will be looking to identify the optimal discharge rate for ensuring battery durability, a very important question to ensure successful V2G operation.

Reviewer 3:
In the reviewer's opinion, the team has clearly identified a list of remaining challenges and barriers, which appear to be appropriate and well thought out.

Reviewer 4:
The reviewer remarked the project progress has already resulted in tests and published work; the future work to complete the project is reasonable for the current state of work. Next tasks involve integrating functional system in vehicle and demonstrating the 30 operational modes.

Reviewer 5:
The reviewer commented the remaining challenges (outlined in Slide 11) are still significant, considering that the project is scheduled to end in June 2020. The reviewer is concerned that no indications are given on the severity of each challenge, and on whether the team has defined a strategy and success metrics to address each of them to a sufficient level of completion. In particular, the Task of assessing the impact of V2G on PEV battery capacity and impedance should not be overlooked in terms of time and effort required.

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

Reviewer 1:
The reviewer said the result of this project will help DOE to clearly generate data on DER applications as well as verify standards for V2G. This will significantly address the future of EVs for grid support.

Reviewer 2:
The reviewer said that the project is focused on advancing technologies necessary for successful implementation and integration of V2G.

Reviewer 3:
The reviewer remarked in order to reduce oil consumption, EV's will require a substantial amount of work integrating into grids, charging, infrastructure, etc. This project approaches and addresses the V2G communication issues that will be associated with charging/discharging from smart grids.

Reviewer 4:
The reviewer stated that the project supports the overall DOE objectives. The V2G technologies addressed in this project particularly support the aspects of "modernize the electricity grid, enhance the security and resilience of energy infrastructure" in the DOE goals and objectives.

Reviewer 5:
The reviewer remarked the project appears to supports the overall DOE objectives of deploying fast-charging infrastructure for PEVs, by conducting a deployment and evaluation program. However, several unknowns still persist regarding the viability of adopting bi-directional V2G integration, as well as the development of certification standards.

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 the team has sufficient resources.

Reviewer 2:
The reviewer remarked the resources allocated for the project are considered commensurate to the level of effort.

Reviewer 3:
The reviewer commented an appropriate level of funding for project and development.

Reviewer 4:
The reviewer stated that the resources for the project are sufficient and the project is on track.

Reviewer 5:
The reviewer said funding appears sufficient at this time, in spite of the requested project extension.

Presentation Number: elt188
Presentation Title: Bi-Directional Wireless Power Flow for Medium-Duty Vehicle-to-Grid Connectivity
Principal Investigator: Steven Sokolsky (CALSTART)

Presenter
Steven Sokolsky, CALSTART

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 and well-planned.

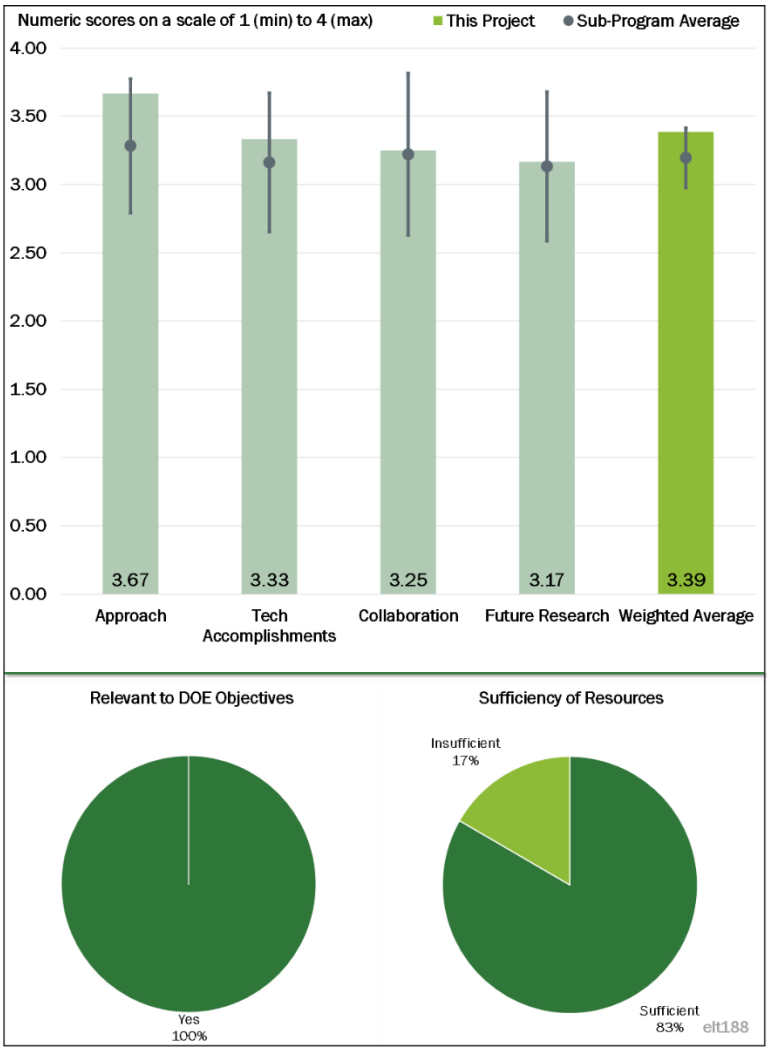

Figure 4-10 – Presentation Number: elt188 Presentation Title: Bi-Directional Wireless Power Flow for Medium-Duty Vehicle-to-Grid Connectivity Principal Investigator: Steven Sokolsky (CALSTART)

Reviewer 1:
The reviewer remarked the approach for the research has been excellent. The team has achieved a very high efficiency for a significant gap of 11 inches. The team is providing a comprehensive, end-to-end solution, which is very unique to this project.

Reviewer 2:
The reviewer commented the approach for a wireless charging medium-duty vehicle is sound and the work done to date is excellent. The reviewer remarked that the work on the design of the electromagnetic coupling coil is efficient by iterating between finite element modeling and validation through actual testing. The work uses actual vehicle battery and grid voltage and power level, making it easy for the future deployment. More importantly, the team promised to test the system on real trucks. The reviewer said that the team is careful enough to build two sets of systems.

Reviewer 3:
The reviewer said that the project team seems to have thoroughly analyzed all of the components necessary and tested them individually. The team has anticipated potential challenges in getting everything to work together.

Reviewer 4:
The reviewer remarked the approach has been on track and results indicate a successful design of the project steps and milestones. After two budget periods, no fundamental approach changes are indicated.

Reviewer 5:
The reviewer commented that the project had a well thought-out approach to address the barriers of wireless power transfer with large air gap, at a high power level, and with bidirectional power flow.

Reviewer 6:
The reviewer said when the principal investigator was asked a question about why such a low transfer rate of 20 KW-hr, the stated answer was because it was all the client needed. It should have been decided based on an analysis of what the collaboration partner would get best value from. It was not clear whether the partner was ever consulted on this matter. The reviewer noted that the build and setup of a demo after the vehicle type changed is the principle cause for delay.

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

Reviewer 1:
The reviewer remarked the team has reported a 96% DC-to-DC efficiency with a gap of 11 inches. This is a very impressive result.

Reviewer 2:
The reviewer noted that in budget period 1, the team completed model, simulation, and analysis of power conversion. System architecture and control modes were designed. Electromagnetic coupling coil (this is a critical milestone that the team hit), resonant tuning, and passive component were all designed. The reviewer said this is a very good achievement and laid the foundation for budget period 2. The budget period 2 work is to build the system designed in budget period 1. The reviewer said it is satisfactory to see the system is constructed from design, to component, then to system (Slide 16). Many nice results were briefly discussed at the AMR. The reviewer noted testing of resonant stage transferring 20 kW power with an 11 inch air gap, with 96% DC-to-DC efficiency is most impressive. This is a truly outstanding work.

Reviewer 3:
The reviewer said the design and hardware execution overachieved target efficiency of wireless power flow between grid and vehicle on bench system. The change in battery voltage from the original design appeared to result in some (minor) delay to project.

Reviewer 4:
The reviewer commented that the project team has made good progress in designing and simulating the wireless power transfer system. The hardware development seems to be delayed. The primary and secondary power stages have been fabricated, but not tested yet, so the reviewer cannot comment on the performance or whether it is meeting the target efficiencies.

Reviewer 5:
The reviewer remarked the technical accomplishments presented were centered on the system issues. There were changes due to vehicle not being as originally assumed, which caused delays in timing. A very detailed discussion was presented of the build and testing of the design to achieve and exceed the efficiency goals. This efficiency measurement was for a bench set up. The reviewer noted that there was no mention about when an in-vehicle system would be measured for efficiency. Just an assumption that it would be similar.

Reviewer 6:
The reviewer reported that extensive design work has been completed, coupling coils have been built, stuff has been measured, and a lot of analysis has been done. The reviewer inquired about what the analysis indicated to the project team. Additionally, for non-specialists, this reviewer requested that the graphics include an explanation of the information presented.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented it appears most of the work is done by ORNL team, while the rest of the team members did not make much contribution. Perhaps in budget period 3, at the system integration and demonstration stage, other team members may play more significant roles

Reviewer 2:
The reviewer said that collaboration in the project team appears seamless as originally designed.

Reviewer 3:
The reviewer said that this project has the right collaborations to achieve a good result. Maximum use of the partners' knowledge needs to be improved. The reviewer said that more interface with the end-user on the operation of the system in the partner's normal workday functions and how it will best benefit the user is needed.

Reviewer 4:
The reviewer observed that the task distribution among the team members is appropriate. However, the reviewer also observed that only CALSTART and ORNL are responsible for the current accomplishments, but did not find UPS, Workhorse, or Cisco have actively engaged yet.

Reviewer 5:
The reviewer said the project has been significantly driven by ORNL. To this reviewer, UPS, Workhorse, and Cisco have limited visibility so far.

Reviewer 6:
The reviewer assumed that all of the analysis was used to inform the circuit builds, because they were built and seemed to work. Including short explanatory captions along with photo labels was suggested by this reviewer; adding more pictures does not necessarily impress reviewers unless what the project team shows and why is understood. For example, the reviewer inquired as to what all of the circuit diagrams showing and why they interesting. As far as the graphs, the reviewer asked whether the measurements show that things work as expected. There need to be verbs in the slides. The reviewer noted that most of the work described is the ORNL analysis and design, and was unclear on what anybody else contributed beyond supplying money and/or trucks.

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 the reviewer's opinion, the team has clearly identified a list of objectives for the next project period, and remaining challenges and barriers, which appear to be well planned.

Reviewer 2:
The reviewer would like to see more collaboration and testing with all the partners listed in the project in a realistic environment.

Reviewer 3:
The reviewer remarked the proposed future research is sound and natural. The reviewer is eager to see the system tested and evaluated with a real medium-duty truck.

Reviewer 4:
The reviewer reported future work includes performing tests and doing more analysis. There is an integration testing milestone coming up, which this reviewer described as a clue. The challenges all seem to relate to what will happen when the system is tested, but the reviewer noted that minimal information is provided.

Reviewer 5:
The reviewer said the plan is to complete the tasks, finish build of the wireless power transfer system, install and get the vehicles on a test demonstration. The reviewer said very logical and correct. Only question is that no mention was given of how data would be collected and reduced during the demo and shared with the end user. The reviewer asked how this is intended to be done.

Reviewer 6:
The reviewer was unclear when budget period 3 was originally targeted to conclude versus current plan. (December 2019 versus March 2020?). There may be limited on-vehicle testing once system integrated on a truck without a further extension of the demonstration and test phase.

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

Reviewer 1:
The reviewer remarked the project is highly relevant to DOE. It addresses a key feature that will be required by EVs to be successful in the market.

Reviewer 2:
The reviewer said the project has a good chance in creating a commercial product enabling efficient and cost-effective wireless charging for EVs. This work directly and solidly addressed the overall DOE goal on reducing the barriers in vehicle electrification, wireless charging, and V2G integration for improved V2G operations.

Reviewer 3:
The reviewer pointed out that successful wireless power transfer would help enable a transition to electric power in the commercial vehicle sector, which would enhance national security.

Reviewer 4:
The reviewer remarked the project does support relevance and will exhibit a fully functional wireless charging system for medium-duty vehicles. It supports the goal of energy use reduction.

Reviewer 5:
The reviewer said wireless power transfer to/from a commercial vehicle is relevant as a technological enabler for future EV deployments in commercial fleets. The error-proofing and labor saving of not requiring active driver plug-in of commercial vehicles at depots may become a future standard for wide deployments.

Reviewer 6:
The reviewer stated that the project supports the aspect of transportation electrification in the overall DOE objectives. In addition, the bi-directional power flow feature of the proposed wireless power transfer system enhances grid resilience.

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 are sufficient and the project is on track.

Reviewer 2:
The reviewer said resources are sufficient.

Reviewer 3:
It appeared to this reviewer that most of the project effort was on modeling, design, and analysis. The actual physical equipment is limited, beyond the trucks.

Reviewer 4:
The reviewer said the presenter made it clear that the team has sufficient resources. The reviewer sees no reason to question that except to ask who will be the demo data analysis team.

Reviewer 5:
The reviewer said no indication of any resource level mismatches to complete the project in a modified timeline as presented.

Reviewer 6:
The reviewer remarked while the spending at the designing stage and component testing stage seems reasonable, the team should expect much large spending at the system stage where a large system will be built and tested extensively in a realistic environment. There is also a possibility of revisiting the system design stage for improvement. The reviewer sees a request for a plus-up of funding is coming.

Presentation Number: elt189
Presentation Title: Electric Truck with Range-Extending Engine (ETREE)
Principal Investigator: John Kresse (Cummins)

Presenter
John Kresse, Cummins

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 and well-planned.

Reviewer 1:
The reviewer said the approach is outstanding. The project has identified the vehicle utilization requirements and operational goals. These utilization requirements drive the powertrain design requirements. The project also conducts track testing prior to demonstration of the technology in real operation with project partners. The reviewer said any results obtained from the on-road operation can be valuable to refine the powertrain/battery design requirements as well as future modeling for Class 6 technologies. Additionally, the approach clearly shows the cost considerations in comparison to a purely all-electric design.

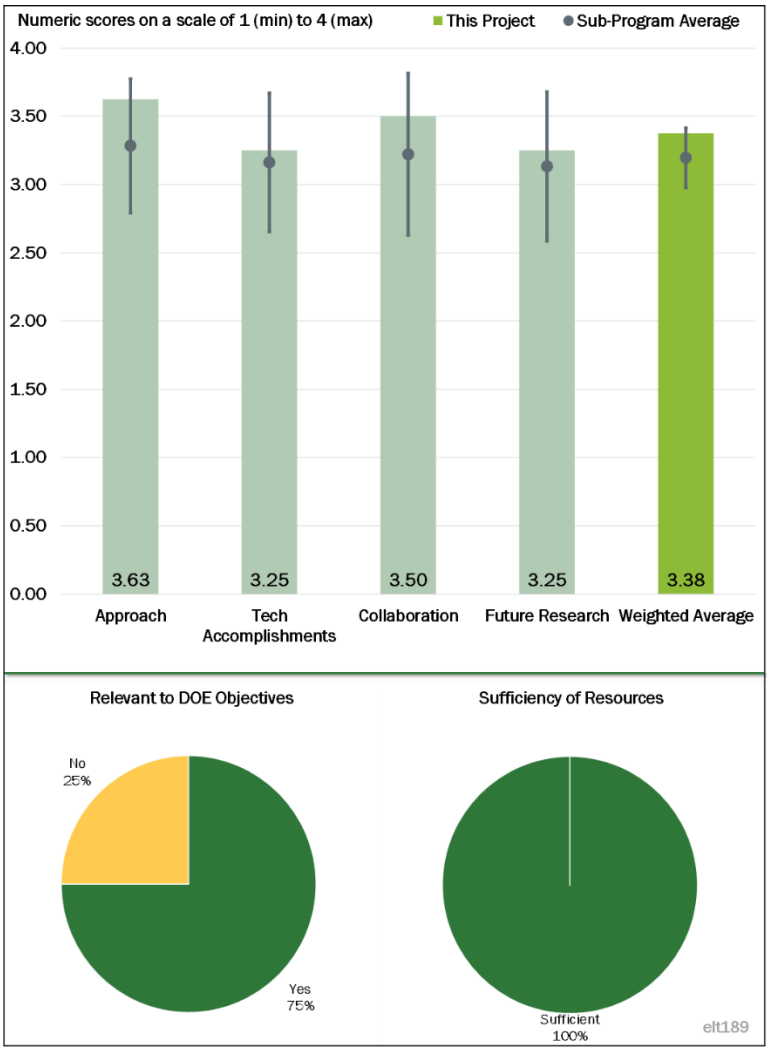

Figure 4-11 – Presentation Number: elt189 Presentation Title: Electric Truck with Range-Extending Engine (ETREE) Principal Investigator: John Kresse (Cummins)

Reviewer 2:
The reviewer said the approach—with a drivetrain supplier leading and a commercial customer as the demo provider—gives the best chance for success. The technical choices were the cause of a time delay due to battery issues, but those have been overcome.

Reviewer 3:
The reviewer said this is a great approach to understanding a "cheap" hybrid, electric based. We need to keep progressing hybrid electric vehicles (HEVs) while developing battery electric vehicles (BEVs). Design to prototype to testing and actually deploying to a customer. Full project is the approach needed and when an engineering team actually is forced to deliver to a customer to haul real freight, it is a much more serious project.

Reviewer 4:
This reviewer stated that using a 4.5-liter diesel engine with selective catalytic reduction (SCR) to power a generator seems counter-productive.

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

Reviewer 1:
The reviewer said the project is on track and appears to be able to meet all goals.

Reviewer 2:
The reviewer described the project as back on track after battery issues and reported that the trucks have been produced and there is confidence in handing over to Frito Lay.

Reviewer 3:
The reviewer said the project results show the decision to develop a new battery pack was successful as indicated by successful operation for track testing. Outstanding results showing correlation between track test results and National Renewable Energy Laboratory (NREL) duty-cycle modeling results. The technical accomplishments score could be higher if more on-road operation (by fleet partners) was accomplished. The milestone / schedule shows the project is a little behind the plan. A significant amount of time (approximately one year) for on-road operation across a wide range of operating conditions (temperature, driver variability, load variation) will provide results and validation to demonstrate the success of the project.

Reviewer 4:
This reviewer said the project is behind schedule and time cannot be made up. Components have been found to be overweight, which affects achievement of the fuel economy goal. The principal investigator has created an understanding of what needs to be changed for serial production and this is a worthwhile achievement. The transmission, battery, and range extender generator are examples. It was found that for cold or hot climates the range extender is engaged to stop de-rating of the power flow. This would have compromised overall performance.

The new battery is being internally sourced from the principal investigator's material handling equipment group. J1526 is a technical challenge (Slide 15) that must be overcome.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer stated that this is a very strong team.

Reviewer 2:
This reviewer said the project has been designed as a commercialization program and has a full range of stakeholders who are all participating. Excellent collaboration.

Reviewer 3:
The reviewer stated that there is evidence of very strong collaboration up and down the supply chain with the partners on this project.

Reviewer 4:
The reviewer said the project clearly showed the scope of work and results from Cummins, PACCAR, NREL, Southwest Research Institute (SwRI), and The Ohio State University from the predicted results, track results, publications, and planned further track evaluation in 2020. However, the scope of work by the other partners is not clear. The reviewer said perhaps the simulation efforts were only in the first year of the project. (Likely described in previous year presentations)

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 proposed future research is strong. The project team proposes to finish track testing and maintain close collaboration with Frito Lay as they use the truck. Indianapolis to Cummins in Columbus is close by, so it should be good.

Reviewer 2:
The reviewer said the future work including further track testing and on-road utilization by fleet partners is very important. Investigating all-electric operation in geo-fenced areas will enable good comparative results. However, this reviewer questioned the statistical robustness across the various driving conditions and driver variations given that there are only two vehicles in the project but only one vehicle (Truck 2) will be used in on-road fleet operation by the project partner.

Reviewer 3:
The reviewer said completing the trucks and completing the demo of 12 months is as originally proposed. While seriously delayed, the tasks are still valid.

Reviewer 4:
The reviewer said it is very difficult to justify moving forward with this type of system and return on investment (ROI) issues.

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

Reviewer 1:
This reviewer said the project does support the U.S. Department of Energy (DOE) mission in advancing transportation systems of goods and services with reduced energy consumption.

Reviewer 2:
The reviewer stated that we must keep working on HEVs, not just BEVs, for all the reasons the principal investigator mentioned.

Reviewer 3:
The reviewer said the original objective was to develop a commercially viable system that reduces fuel consumption by 50%. The research done has created a path to that end, but this specific system must be updated and redesigned using the knowledge gained from the program. This reviewer's opinion is that it will not meet this objective due to design limitations.

Reviewer 4:
This reviewer did not see the energy savings in running a diesel generator.

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 development, evaluation, and demonstration of this extended-range electric Class 6 truck is a significant project. Two vehicles are built for testing and demonstration. The funding appears to be sufficient to accomplish the project goals. A few technical challenges have occurred during the project and the project team has conquered the issues.

Reviewer 2:
This reviewer said the awardee has committed to fund completion of the program with sufficient resources.

Reviewer 3:
The reviewer said sufficient resources.

Reviewer 4:
The reviewer remarked resources are sufficient.

Presentation Number: elt190
Presentation Title: Medium-Duty Urban Range Extended Connected Powertrain (MURECP)
Principal Investigator: Alexander Freitag (Bosch)

Presenter
Alexander Freitag, Bosch

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 and well-planned.

Reviewer 1:
The reviewer stated that the deep integration of electric drive with planetary gear transmission system as a means to achieve and demonstrate 50% fuel consumption reduction in light-duty delivery vehicles is an excellent approach. Modeling coupled with dynamometer testing before the vehicle test is a good way to execute the project.

Reviewer 2:
The reviewer said this project has a logical approach to performing the 50% fuel economy improvements.

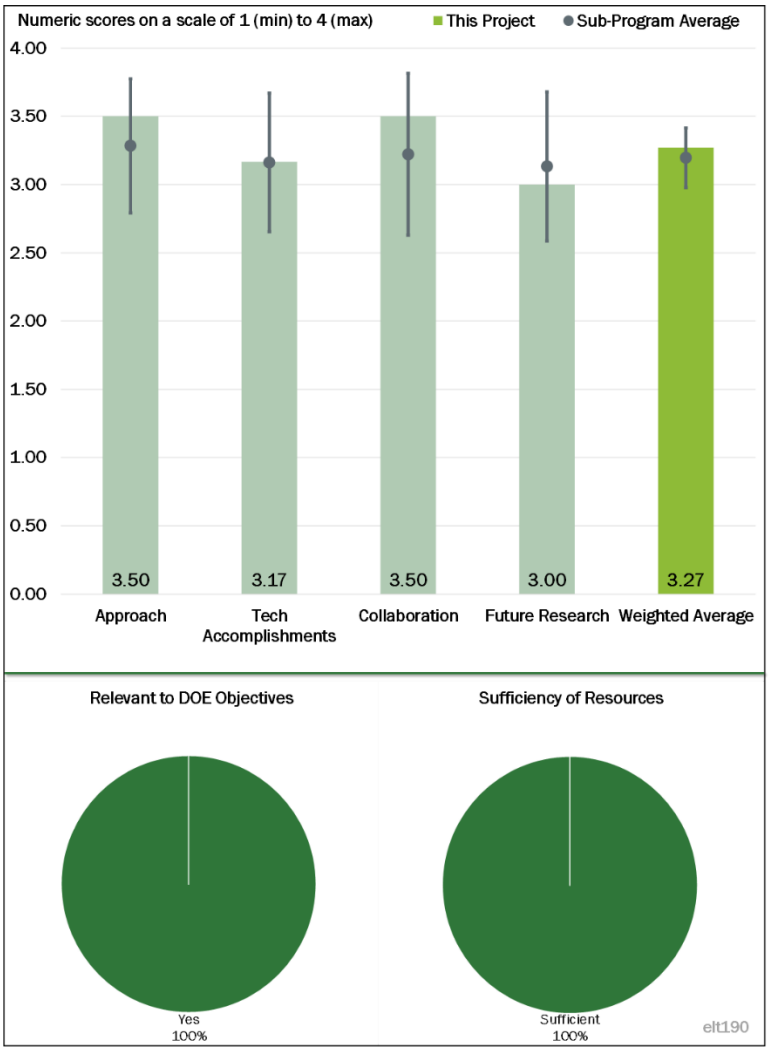

Figure 4-12 – Presentation Number: elt190 Presentation Title: Medium-Duty Urban Range Extended Connected Powertrain (MURECP) Principal Investigator: Alexander Freitag (Bosch)

Reviewer 3:
This reviewer said the project has a solid approach of modeling, followed by design to targets, followed by hardware dynamometer, then in-vehicle phases.

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

Reviewer 1:
This reviewer said that although there are delays in some of the tasks and milestones, reasonable progress was made on the project. The issues responsible for the delays are being addressed.

Reviewer 2:
The reviewer said that some technical glitches (hardware failures in development) are not too uncommon. The other reasons for delays are less understood: availability of truck hardware; and availability/preparation of wiring harnesses. Both of these items appear to have been avoidable with focused program management after 2+ years into the project.

Reviewer 3:
This reviewer stated that the technical problems with the transmission should have been caught in design.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said that a very strong team has been assembled.

Reviewer 2:
The reviewer said that although many participants in the project are listed (including vendors and support organizations), the project lead was effective in integrating the contributions by various project participants. The role and contributions by each participant is clearly articulated.

Reviewer 3:
This reviewer suggested that coordination across the project team of hardware deliverables seems to be an opportunity area if it helped cause delay.

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 stated that ROI has to be clearly defined before further research continues.

Reviewer 2:
This reviewer anticipates that more time will be required to fully integrate into the truck and collect meaningful data in a real fleet(s). There is no indication as to a final customer that has agreed to incorporate into their operation. The reviewer asked whether this has been determined. It is late to start the discussions if intending to deploy in under 6 months...perhaps this is solved but not reported in the status report.

Reviewer 3:
The reviewer said that although "fixes" were implemented for many observed failures in transmission systems, it is clear there is an issue on reliability in the current design. The fixes are only a "Band-Aid," and a more robust solution is needed to mitigate the failures. Also, higher than expected churning losses were observed in the transmission; there was no specific plan to reduce these losses in the future plans.

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

Reviewer 1:
The reviewer said the primary overall objective of DOE is reduction of fuel consumption in different types and classes of vehicles. The project's goal of demonstrating 50% reduction in fuel consumption in Class 4 delivery vehicles will certainly be in support of DOE objectives.

Reviewer 2:
The reviewer stated that these projects have low odds to organically evolve without DOE subsidy or area of interest identification. Professional fleets have a large footprint on fuel consumption and are an outstanding opportunity to correctly match electrification to duty cycles to optimize efficiency improvement.

Reviewer 3:
The reviewer stated yes, 50% can be saved; the cost to do so is needed.

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

Reviewer 1:
The reviewer said the resources provided are sufficient for the project.

Reviewer 2:
This reviewer said there are sufficient resources for the project.

Reviewer 3:
The reviewer remarked there is no indication of concern with resources to complete the project. However, the delays (beyond technical transmission failures) may be a symptomatic of an under-staffed project management to get ahead of the curve.

Presentation Number: elt191
Presentation Title: Medium-Duty Vehicle Powertrain Electrification and Demonstration
Principal Investigator: Wiley McCoy (McLaren)

Presenter
Wiley McCoy, McLaren

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 and well-planned.

Reviewer 1:
The reviewer reported that the approach is to design and develop a plug-in hybrid powertrain, build four demonstration vehicles, and run a demonstration of performance, cost, and reliability for a period of 12 months. It is the most effective way to run this project with required redundancy.

Reviewer 2:
The reviewer said the research team integrated well-known powertrain electrification technologies to a complete vehicle, which is currently ready for demonstration, which is very good. As described in the presentation, the technology can be conveniently used as a retrofit into traditional vehicles, although the difficulties and challenges for such has not been reported. The team did not provide new technologies developed in this research, which was not technically available before this project was started.

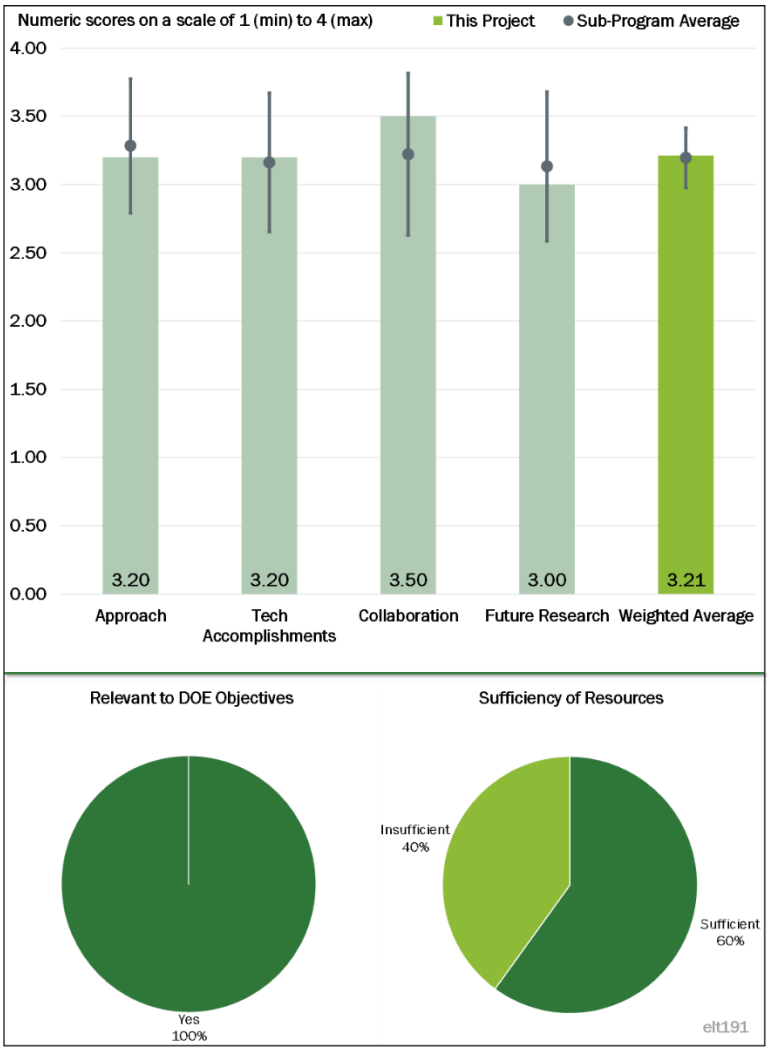

Figure 4-13 – Presentation Number: elt191 Presentation Title: Medium-Duty Vehicle Powertrain Electrification and Demonstration Principal Investigator: Wiley McCoy (McLaren)

Reviewer 3:
The reviewer noted the program has been delayed significantly in the deployment and testing phase by unforeseen problems that required redesign of different vehicle components. Nevertheless, the team plans to follow through with Phase 3 of the program without reducing the scope of work or deliverables. One concern that emerges is that the DOE funds have been almost completely spent, hence there is a risk that the Project Team will not be able to follow through with the remaining Tasks (even if they stated that they will fund the rest of the program internally). The reviewer remarked it would be useful to set specific Milestones for Phase 3, and metrics to evaluate success or partial success, in case the entire set of Milestones cannot be delivered.

Reviewer 4:
The reviewer said that In general, the project follows a contemporary define/design/verify approach, as opposed to the less effective design/build/fix approach. System-level modeling and analysis led to well defined

component-level requirements. Adequate verification testing appears to have been done to identify component and system-level issues. However, it is not clear what process is being followed to resolve component issues, nor is it clear what AVL's role is in resolving the system integration issues. The reviewer commented more information should be shared on the nature of verification testing, especially what the vehicle-level requirements are for drivability, durability, and performance. "Make it like UPS's existing vehicles" is not a sufficiently clear target.

Reviewer 5:
The reviewer said that partially in hindsight the project was too aggressive for the timing proposed. Relative to approach it appears that the modeling phase may have been "cheated" to now discover that a single-motor, single-speed approach is feasible for the application. The science has not changed that much but perhaps the commercial availability of devices has changed (that originally steered the team away from this simpler approach). The reviewer remarked fFor purposes of the DOE research, the optimal most-efficient approach should have been tested despite commercial availabilities.

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

Reviewer 1:
The reviewer said all system issues have been addressed to build a product which will work in the desired vocation.

Reviewer 2:
The reviewer noted that the team appears to have successfully delivered a design that achieves substantial energy efficiency improvement. Because vehicle testing at a fleet scale is still ongoing, the team should consider elaborating a risk mitigation strategy in case the results at the end of the program will not match the data obtained so far.

Reviewer 3:
This reviewer said that although the delivery of this project has been slightly delayed, it is okay for this development and demonstration project, especially because this project involves numerous collaborators including original equipment manufacturers (OEMs). As described in the presentation, the 100% fuel economy (FE) improvement has been achieved in initial testing. However, the research team did not provide any data supporting this statement, so the reviewer is not able to justify this statement with the information presented.

Reviewer 4:
The reviewer noted the project encountered numerous technical setbacks leading to a 7-month Phase 2 delay completion. It is not clear what additional learning could come from these experiences (root causes). Completion of the e-axle and testing on dynamometer is certainly a positive milestone.

Reviewer 5:
The reviewer commented that although the project's Phase 2 (component design and build) was judged as completed, there were numerous design problems that need to be resolved before moving to Phase 3 (vehicle demonstration). Project timing has been delayed multiple times due to engineering issues. While it is important to identify and address these issues, and the team has learned a lot, no information was given on the plan or status of issue resolution.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said the project involves numerous collaborators including AVL, Ford, and UPS. The system is ready for demonstration, and UPS is also well prepared for vehicle demonstration. All evidences supported that this team has done a very good job in collaboration.

Reviewer 2:
The reviewer said a very strong team has been assembled.

Reviewer 3:
This reviewer stated that collaboration across team members appears effective.

Reviewer 4:
The reviewer said the collaboration appears strong. No indication of any disconnects among original team members.

Reviewer 5:
The reviewer said the project has strong partners in UPS and AVL. However, AVL's budget for the project was twice that of Mclaren/Linamar, and their share of federal funding was more than twice as much as the principal investigator, yet no mention of AVL's role in Phase 2 and Phase 3 of the project was made. In reviewing past years' presentations, AVL had a strong role in Phase 1. It is also unclear what role VehNergy has played 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 project has built tools to effectively specify propulsion requirements for this vocation.

Reviewer 2:
The reviewer noted that the remaining Tasks have been described in a sufficiently clear manner. It would be worth considering to expand on the metrics and success criteria, and risk mitigation strategies.

Reviewer 3:
The reviewer said the new plan incorporates the original plan of 12-months testing in the field. This is a positive decision and good faith indication from the primary (Linamar/McLaren). There is no reason to believe that the objectives of the project (other than timing) will be compromised.

Reviewer 4:
The reviewer said the research team has identified the challenges in Slide 10, including the lubrication issues, park lock issues, etc. However, the team did not provide the detailed plan or solution to these issues and the possible difficulties in mitigating these issues.

Reviewer 5:
The reviewer explained that the remainder of the project is mostly focused on vehicle testing, demonstration, and calibration. However, very little detail was given on the approach that will be followed. The presenter remarked that Linamar will be funding the completion of the project, but the presenter failed to describe how the remaining federal funding ($250,000) will be used. This is a non-trivial amount of money and care should be taken to spend it wisely, or to not spend it and make it available for other federal research projects.

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

Reviewer 1:
They reviewer said yes, electrified axles are a very significant advancement in EV Class 4 to 6 vehicles. This should bring reliability and significant cost reduction in building future vehicles.

Reviewer 2:
The reviewer stated this project supports the DOE goals of demonstrating fuel economy improvement solutions for medium duty trucks.

Reviewer 3:
The reviewer said the technology developed in this project is well aligned with DOE objectives in reducing energy consumption and improving the fuel efficiency of transportation system.

Reviewer 4:
This reviewer stated that the project is highly relevant to DOE's objectives.

Reviewer 5:
The reviewer said this project represents another propulsion/vehicle architecture approach to medium truck electrification to improve overall energy efficiency and greenhouse gas emission reduction. This has been part of the DOE intent toward transportation electrification for some years and commercial fleet trucks may afford the greatest near-term payback and likely deployment segment.

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

Reviewer 1:
Sufficient resources for the project.

Reviewer 2:
This reviewer believed that the funding for this project is sufficient for this team to complete the work proposed as scheduled.

Reviewer 3:
The reviewer said the resources seem sufficient on the condition that the primary grant recipient (Linamar/McLaren) subsidizes the extended project timeline including maintaining the 12-month demonstration phase.

Reviewer 4:
This reviewer said that due to the unforeseen problems, the project will require leveraging internal funds and resources to be completed. This poses a risk of partial completion of the remaining tasks.

Reviewer 5:
This reviewer said the resources of the project have clearly been insufficient, because the original budget has been spent prior to project completion. It is admirable that Linamar will fund the remainder of the project so the technology can be successfully developed and commercialized.

Presentation Number: elt197
Presentation Title: High Power and Dynamic Wireless Charging of Electric Vehicles (EVs)
Principal Investigator: Veda Galigekere (Oak Ridge National Laboratory)

Presenter
Veda Galigekere, Oak Ridge 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 and well-planned.

Reviewer 1:
The reviewer stated that the approach is sound and the plan is well laid out

Reviewer 2:
The reviewer said the three partners have divided up the work and are working well in parallel to design build and validate a dynamic wireless charging system. The partners each have clearly defined goals and tasks.

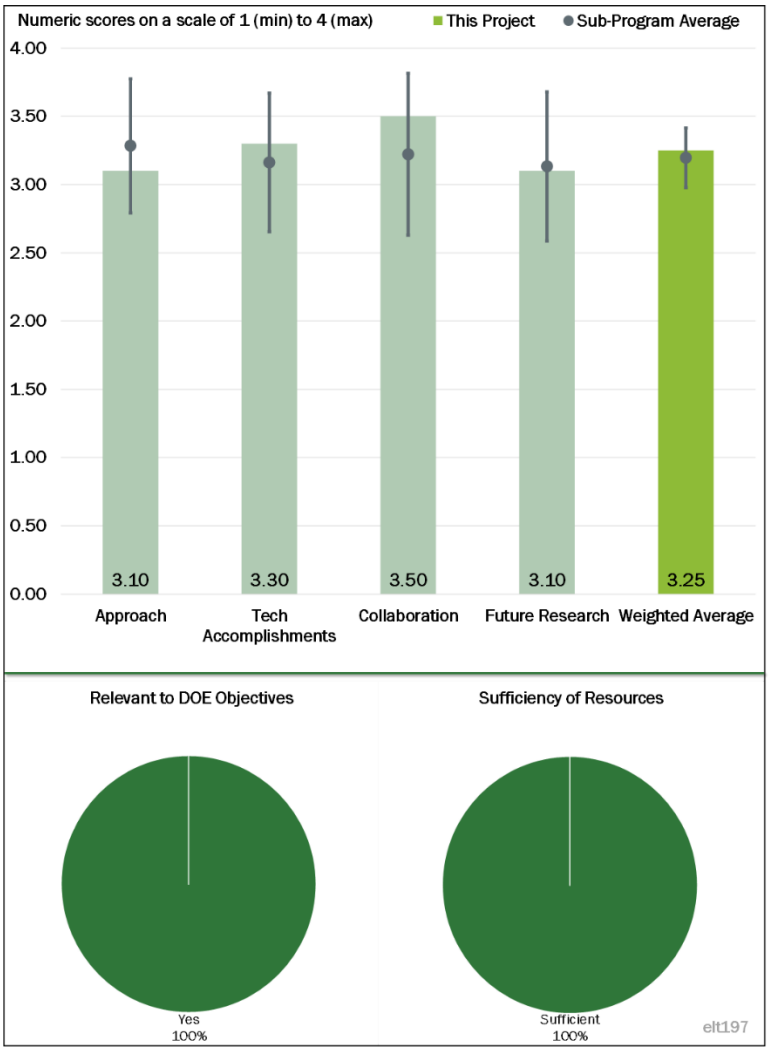

Figure 4-14 – Presentation Number: elt197 Presentation Title: High Power and Dynamic Wireless Charging of Electric Vehicles (EVs) Principal Investigator: Veda Galigekere (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer stated that the approach seems promising. Because it is in simulation stage, its feasibility cannot be confirmed at this stage. The technical barriers have not been addressed accurately. The broad term "novel" was mentioned as the required steps, but there were no details of how the proposed method/s address the issues and how it is novel.

Reviewer 4:
The reviewer noted that Slides 18 and 19 indicate that dynamic wireless power transfer (DWPT) has a lower overall cost compared to static wireless power transfer (SWPT) and direct current fast charging (DCFC). This conclusion appears to be a strong function of the assumptions that were made. This reviewer may not completely agree with the use of real-world data to model vehicle energy consumption. The real-world data tends to target the 50th percentile driver. When an OEM designs a vehicle, it is designed for the 95th or 99th percentile customer in terms of durability. However, every one of the vehicles would have to meet its performance specification. If it is supposed to be able to climb a 35% grade (for instance), then everyone one of that particular model should be able to do that. DWPT would have to provide the driver the freedom to drive anywhere she wants—and this means that if the driver drives the vehicle on some tertiary roads, it would still

need to have the expected range. The reviewer remarked if the DWPT system has to be democratic and provide everyone equal access to electrified roadways, the cost would perhaps be much higher.

Reviewer 5:
The reviewer stated the infrastructure cost question looms over this project. It is one thing to demonstrate DWPT for sake of developing knowledge on tech feasibility, but the project claims to be determining feasibility given all the constraints involved, including cost. The reviewer asked how the most cost-effective system design can be determined if there is so much uncertainty.

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

Reviewer 1:
This reviewer noted that this is a new project starting in 2019. The presented achievements and milestones are on track.

Reviewer 2:
The reviewer said that each partner has either completed or is on track with their stated goals.

Reviewer 3:
This reviewer said that generally, very good progress has been made. In the fiscal year (FY) 2019 NREL timeline, Task 5 should have been moved up to before Task 1. The first step should have been to evaluate whether DWPT is the best approach, when compared to other existing approaches.

Reviewer 4:
The reviewer stated that there has been a lot of excellent progress on most aspects of the project. This reviewer thinks the infrastructure piece needs to be at the forefront.

Reviewer 5:
The reviewer stated that this is a new project. There has been little progress to date.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that all partners appear to be communicating and working well together.

Reviewer 2:
This reviewer said there is excellent coordination between the National Laboratories. It would be good if the principal investigator could elaborate a little on the roles of the other partners: Mercedes-Benz R&D, Utah State University, Magment, and Integrated Roadways.

Reviewer 3:
The reviewer said collaboration is good. This reviewer would like to see some roadway construction expertise.

Reviewer 4:
The reviewer stated that the team looks good, but there has not been significant collaboration on the project yet.

Reviewer 5:
The reviewer said the collaboration is among Oak Ridge National Laboratory (ORNL), National Renewable Energy Laboratory (NREL) and Idaho National Laboratory (INL). Some other partners have been also motioned, such as—Mercedes-Benz Research and Development North America, Utah State University (characterization of mechanical and civil engineering aspects of wireless power transfer [WPT] coils), Magment (a company that manufactures magnetic cement), Integrated Roadways (characterization of

properties of pavement per dynamic WPT requirements)—but the level of engagement, involvement, collaboration, or technical feedback is 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 the proposed future work is highly appropriate.

Reviewer 2:
The reviewer said the proposed future research is well planned and documented. This reviewer thinks that the plan is aggressive and may be difficult to accomplish.

Reviewer 3:
The reviewer said the partners (ORNL, NREL, and INL) have defined tasks to accomplish the overall project goals. The future work proposed is a logical extension of what the team has currently accomplished.

Reviewer 4:
A couple of points that this reviewer would like to see addressed better: 1) The cost of the DWPT system is also a function of the degree of penetration of EVs, the cost and power density of batteries in the future, and the architecture of the light duty (LD) vehicles in the future. The reviewer asked if there are there scenarios where DWPT offers cost benefits and scenarios where DWPT is not advantageous. 2) Northern states and cities go through several freeze-thaw cycles every winter. These take a heavy toll on the roads, causing huge potholes. Roadways are heavily salted to prevent ice buildup. The reviewer asked how these impact the DWPT systems.

Reviewer 5:
The reviewer stated that the proposed solutions are not mature yet and do not cover all presented challenges/barriers. For example, it is not clear how the controller will be developed based on time-varying simulation model. Another example is the lack of a clear future plan for an accurate cost model. Also, the solutions for electromagnetic (EM) shielding effects and required interface are missing.

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

Reviewer 1:
The reviewer noted that the objectives outlined in this presentation match well with the priorities of DOE.

Reviewer 2:
This reviewer said that dynamic vehicle charging will, if implemented, enable smaller and lighter battery packs in vehicles. For this reason, the reviewer believes this project is well aligned to the DOE objectives.

Reviewer 3:
The reviewer stated this project potentially advances EV technology adoption if proven feasible.

Reviewer 4:
The reviewer said the project will analyze, design, build, and validate a vehicle-integrated high-power and dynamic wireless electric vehicle (EV) charging system, which is viable when applied to real-world traffic conditions in the United States. Enabling electric drive vehicle (EDV) technology is what supports the DOE objectives.

Reviewer 5:
The reviewer said that if DWPT leads to better adoption of EVs, that would generally support the DOE objective. However, if DWPT systems have significantly lower overall efficiency—that could lead to a lot of wasted energy.

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 appear to be sufficient, as of now.

Reviewer 2:
Resources appeared adequate to this reviewer.

Reviewer 3:
The reviewer noted that this is just the start of the project, and the provided resources seem to be sufficient to support the execution of the project.

Reviewer 4:
This reviewer observed all parties to be working well together and asked whether the weight should be 10% as opposed to 0%.

Reviewer 5:
This reviewer believes that the project is quite aggressive and may require additional resources to reach a successful conclusion. However, the PI felt the resources were adequate.

Presentation Number: elt198
Presentation Title: Cybersecurity: Securing Vehicle Charging Infrastructure - SNL
Principal Investigator: Jay Johnson (Sandia National Laboratories)

Presenter
Jay Johnson, Sandia National Laboratories

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 and well-planned.

Reviewer 1:
The reviewer said the Sandia research team has very deep knowledge of the subject matter. The Sandia team has delivered a strong graded approach to identifying potential threats to EV charging infrastructure, in addition to evaluating the severity and impact of those threats in relation to critical electrical infrastructure. Researchers are commended for their recognition of industry needs and using that information to guide their approach and adjust or re-scope where appropriate.

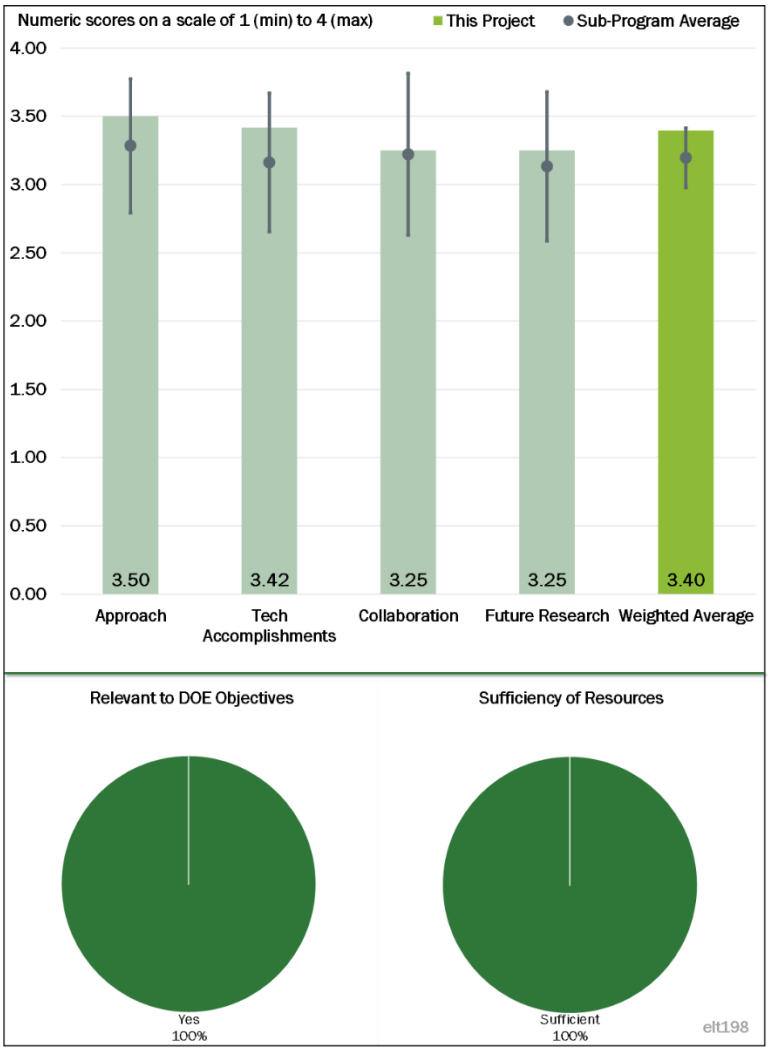

Figure 4-15 – Presentation Number: elt198 Presentation Title: Cybersecurity: Securing Vehicle Charging Infrastructure – SNL Principal Investigator: Jay Johnson (Sandia National Laboratories)

Reviewer 2:
The reviewer said the project appears to have a rational approach to addressing a complex problem. The project team is appropriately including an evaluation of best practices in the cybersecurity area, along with a detailed look at the special needs of electric charging infrastructure. This detailed look includes not only the vehicle and charging systems portions, but also the power system impact. This will be critical to ensuring a more complete investigation takes place. Also included in the project is interviewing industry, to both identify best practices and gain perspective.

Reviewer 3:
The reviewer noted that the primary goal of this project is to protect U.S. critical infrastructure and improve energy security through technical analysis of the risk landscape presented by massive deployment of interoperable EV chargers. The objective is to create a cybersecurity threat model and perform a technical risk assessment of electric vehicle supply equipment (EVSE), so that automotive, charging, and utility stakeholders can better protect customers, vehicles, and power systems in the face of new cyber threats. This project is laying a foundation for securing critical infrastructure by: 1) conducting adversary-based assessment of charging equipment, 2) creating a threat model of EV charging, and 3) analyzing power system impacts for different attack scenarios.

The reviewer noted that the project has identified several technical barriers/gaps including: 1) poorly implemented EVSE cybersecurity is a major barrier to EV adoption, 2) no comprehensive cybersecurity approach and limited best practices have been adopted by the EV industry, and 3) an incomplete industry understanding of the attack surface, interconnected assets, and unsecured interfaces. This project is directly addressing technical barriers/gaps number 2 and 3 just mentioned. The project is broken into two tasks. Task 1 (vulnerability assessment and threat model development) includes identifying EV charging components and information flow; Spoofing, Tampering, Repudiation, Information disclosure, Denial of service, and Elevation of privileges (STRIDE) threat model creation; and development of an attack graph and threat matrix. Task 2 (investigate consequences associated with charging/vehicle vulnerabilities) includes EV cyber-attack impact analysis on distributed utility systems and an impact analysis on transmission systems. Ultimately, both tasks coalesce into the end goal of creating a risk matrix and prioritization of mitigations. Two key milestones have been established. Overall, this project is addressing technical barriers, is well-designed, and clearly feasible.

Reviewer 4:
The reviewer noted a generally thorough methodology. This reviewer would have liked to see a commercial cybersecurity firm as consultant or partner.

Reviewer 5:
The reviewer said this project needs fleet partners and telematics manufactures to bring more "real world" applications uses.

Reviewer 6:
The reviewer noted three strengths of the project: First, use of STRIDE Threat Modeling to identify key elements of the system, their interconnections and interrelationships, and the Trust Boundaries was excellent and covered many of the key concerns for both the plug-in vehicle (on-board) and the EVSE (off-board); second, use of attack graphing to indicate entry points, staging areas, and consequences was also very informative and useful, as were simulations of the impact on the distribution system; and third, impact scenarios for load drop conditions due to simultaneous charging termination was well explained.

The reviewer noted two weaknesses of the project: First, there could have been more specific information on the inputs to the risk matrix which was just presented here as a definition of the standard risk priority approach; second, the work seemed focused on denial of service to multiple charging stations as the main consequence of an attack. The potential for other attack modes (e.g., supplying the wrong voltage, supplying too high a current leading to a fire on the vehicle) were not addressed.

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

Reviewer 1:
The reviewer stated that this presentations shows excellent progress on threat analysis and network impact assessment of critical scenarios.

Reviewer 2:
The reviewer said the team seems to have done a thorough analysis of potential threat paths, in a highly complex environment. The analysis is not based just upon individual vehicles, but also the methods for attacking a fleet of vehicles and the impact on power systems (including a number of voltage profiles). The project is conducting a detailed transmission system consequence analysis to determine whether a regional grid could be significantly affected at large load drops. A draft overall power systems consequence risk matrix was developed to assess potential threats.

Reviewer 3:
This reviewer said the Sandia research team developed a detailed and logical map of the threat model for both plug-in electric vehicles (PEVs) and charging infrastructure. This threat model will be a valuable tool for

industry when determining what communication pathways need to be secured and which stakeholders must be engaged when developing new charging technologies. Defining the cybersecurity pathways from charging infrastructure to critical utility infrastructure will help establish industry best practices and drive to a more secure charging ecosystem.

Reviewer 4:

This reviewer noted the project has achieved progress and several notable technical accomplishments. First, development of the draft STRIDE Threat Model of EV Charging. This STRIDE model includes the detailed processes, data flows, end points, trust boundaries, and electrical equipment affecting the cybersecurity of EV/charging infrastructure. It incorporates information from the EV information flow chart, VTO workshop (Electricity Subsector Cybersecurity Capability Maturing Model [ES-C2M2]) results, vulnerability/common vulnerabilities and exposures (CVE) announcements/disclosures, and U.S. Department of Transportation (DOT) Volpe threat model. It covers the vehicle, EVSE/EVSE service provider, and buildings/utilities sides of the landscape, including trust boundaries. The reviewer asked whether the threat model will be somewhat different depending upon the EVSE charging levels (Level 2 [L2], DCFC, and extreme fast charging [XFC]). Second, the project developed EV charging attack graphs. These attack graphs show attacker actions to achieve an objective and illustrate access points, staging areas, and consequences of concern. The attack graphs graphically illustrate the steps an attacker must take to move from system/network access to the consequences of concern. The major concerns identified are whether an attacker can pivot between components, systems, and networks in the EV/EVSE to compromise the necessary information flows and can an attacker synchronize their attack to affect portions of the grid simultaneously. Third, distribution system and transmission systems impact analyses and consequences. The reviewer remarked the project completed a consequence study mapping of EV/charging potential vulnerabilities to the power system and other critical infrastructure impacts. Results indicate that unity charging is within utility feeder voltage limits defined by the American National Standards Institute (ANSI) C84.1, grid support features can help improve (or hurt) the voltage profile, and several scenario cases were outside of ANSI C84.1 Range A while two case were outside of ANSI C84.1 Range B. The transmission system consequences look at the Western Electricity Coordinating Council (WECC) and modelled load drop worst case scenarios (10 gigawatt [GW] simultaneous load drop). Results indicate no voltage or frequency limits were exceeded. Fourth, Risk Matrix and Remediation Prioritization: For each attack scenario, the likelihood of success and potential power system impact is being used to estimate risk. The project is identifying the highest risk scenarios to inform DOE and industry of mitigation priorities. Overall, the project has demonstrated strong progress with a number of technical accomplishments.

Reviewer 5:

The reviewer said the presentations shows very good work on analytics. Practical applications need to be addressed.

Reviewer 6:

This reviewer said that the Progress and Technical Accomplishments seemed very good for a project of limited scope and duration (12 months) focusing specifically on identifying potential EV charger vulnerabilities and risks to critical infrastructure. The graphs and threat models were very detailed in identifying these risks and vulnerabilities and the example of a transmission system attack was useful in visualizing some of those risks. However, much additional work in this area is needed beyond current scope to address many of these issues and to develop remediation methods.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:

The reviewer said this project includes many of the key team members appropriate for this project, including not only DOE National Laboratories, but also the DOT Volpe Center and industry partners. The project has also worked to inform other key Federal agencies such as the U.S. Department of Homeland Security (DHS), Navy, and Army, among others, opening up additional opportunities for collaboration in the future. The

principal investigator indicated that the industry partners have been particularly open to working with the project.

Reviewer 2:
The reviewer stated that partners and collaborators in this effort were well chosen to complement each other and to address all facets of the work. In addition, the partnerships and collaborations between National Laboratories and with industry and government appeared to be strong, based on the quantity and quality of the work. However, the roles played by each of the partners could have been specified in more detail.

Reviewer 3:
This reviewer said the project team appears to have very good collaboration. However, the team is short critical members to achieve success.

Reviewer 4:
The reviewer stated the project team includes appropriate expertise from various organizations. However, the reviewer did not see a commercial cybersecurity connection for potentially greater diversity in views.

Reviewer 5:
The reviewer said it is unclear what roles the two supporting National Laboratories (Pacific Northwest National Laboratory [PNNL] and Argonne National Laboratory [ANL]) will carry out in the project; however, the other government agency and industry collaboration seems on point. The project is seeking input from key government agencies such as military, national security, and energy security and emergency management which should provide for a rich cross-section use cases.

Reviewer 6:
The reviewer noted that the project partners include Sandia National Laboratories (SNL), PNNL, ANL, DOT Volpe Center, National Motor Freight Traffic Association (NMFTA), and BTCPower— a relatively broad and inclusive list of National Laboratories, government agencies, an association, and industry. No real mention is made of collaboration and coordination amongst the team members, nor specific roles within the team. While they would not necessarily be considered team members, it would probably be good to enlist as many salient outside entities as possible to review and comment on the STRIDE threat model, attack graphs, and transmission/distribution system impacts, and consequences. These entities could include auto/truck OEMs, additional EVSE manufacturers/cyber network operations (CNOs), other associations, building management entities, and utilities. The broader the perspective and more early eyes on these areas the better, leading to more robust and validated results from which to build.

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 next steps are appropriate.

Reviewer 2:
The reviewer stated the project has identified a number of important items for future research. The project is currently negotiating which proposed future research activities will be conducted under this project (as extended), and which will be under future projects. The principal investigator indicated that industry has indicated the nearer-term need is for basic elements, such as policies and determining some of the questions that need to be asked of vendors.

Reviewer 3:
The reviewer stated that designing defense systems from the project findings is the most important part of this work.

Reviewer 4:
The reviewer said the planned future research outlined in the Remaining Challenges and Barriers Slide covers most of the key areas for additional study and many of the elements of a remediation strategy that must be developed. However, a full description of these methods and why they were chosen over alternative developments was not clearly stated.

Reviewer 5:
The reviewer said a cornerstone of the project is the development of standardized policies for managing chargers and other assets in the charging ecosystem. The project should clearly define the platform for which these policies will be shared with industry. It is unclear how relevant the proposed creation of hardware-and-software-based fallback and contingency operating modes will be to industry, and the likelihood of adoption among industry. The project resources should be focused on standardized policies and response mechanisms.

Reviewer 6:
The reviewer said the presentation does not extensively elaborate on proposed future research for this project, leaving the reviewer a little in the dark about future directions. The presentation does mention that risk assessments are the beginning of a comprehensive approach to cybersecurity that will include a number of other general elements including standardized policies, perimeter defenses, situational awareness and intrusion detection systems, response mechanisms, and contingency operating modes. But, the presentation does not mention specific next steps for this particular project. Given the large number of potential vulnerabilities and attack surfaces of EV/charging systems, it may be good to initiate identification of the most vulnerable access sites to begin research for development of defenses. The PI did mention during the presentation that initially focusing on the power modules and trust boundaries probably makes sense.

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

Reviewer 1:
The reviewer said that cybersecurity is one of the most critical infrastructure elements necessary to the successful large scale adoption of EVs. Given the limited range of vehicles and the need for repeated charging, the ability to trust that charging services will be available when needed is a crucial element in selecting an electric car. This makes cybersecurity a very important element in supporting the overall DOE objectives.

Reviewer 2:
This reviewer said the project appears to be establishing a baseline of performance for EV charging cybersecurity, which will inform and guide VTO's broader portfolio for vehicle cybersecurity. From the presentation, it is clear the EV charging industry is in need of these top level definitions and will benefit from the project's research objectives. Creation of the threat model will help industry define the EV charging ecosystem and determine what sector is responsible for securing what section of EV charging.

Reviewer 3:
The reviewer said that as the United States transitions to transportation electrification, cyber-attacks on vehicle charging could impact all U.S. critical infrastructure. As a first step, this project is establishing a baseline threat model and vulnerability assessment, and will provide a foundation to inform and support future R&D efforts to secure charging infrastructure from cyberattack. As such, it will help enable further introduction of PEVs into the nation's transportation fleet, which will lead to concomitant energy savings, emissions reductions, and increased national security, all of which support VTO and DOE objectives.

Reviewer 4:
The reviewer said the relevance is that we need a strong cybersecurity approach to ensure that EV development and deployment keeps moving forward at a rapid pace.

Reviewer 5:
This reviewer stated that EVSE security is an important problem to address, particularly as charge points proliferate and go to much higher power levels.

Reviewer 6:
The reviewer noted that this project is focused on a particular concern for widespread adoption of EV technologies—developing a greater understanding of how to secure vehicle charging infrastructure.

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 sufficient resources for the project.

Reviewer 2:
The reviewer commented resources appear to be adequate.

Reviewer 3:
The reviewer remarked resources seem adequate to accomplish the work.

Reviewer 4:
The reviewer noted that this is a 1-year, $1 million, non-cost share project, which appears to be on schedule having largely completed its first two major milestones. Ostensibly, no mention of funding constraints has been made. As such, the project seems sufficiently funded and is positioned to complete its requirements on schedule by September 2019.

Reviewer 5:
The reviewer said that for now, the resources appear sufficient, but that depends upon what future activities are ultimately included in the re-negotiated scope. The project has begun to identify a vast amount of additional research needs in this area—this project has only just opened the door here.

Reviewer 6:
The reviewer observed that as this is primarily a paper study, the resources seemed appropriate for this project to make good progress and for completion of this effort.

Presentation Number: elt199
Presentation Title: Cybersecurity: Consequence-Driven Cybersecurity for High-Power Charging Infrastructure - INL
Principal Investigator: Richard Carlson (Idaho National Laboratory)

Presenter
Richard Carlson, 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 and well-planned.

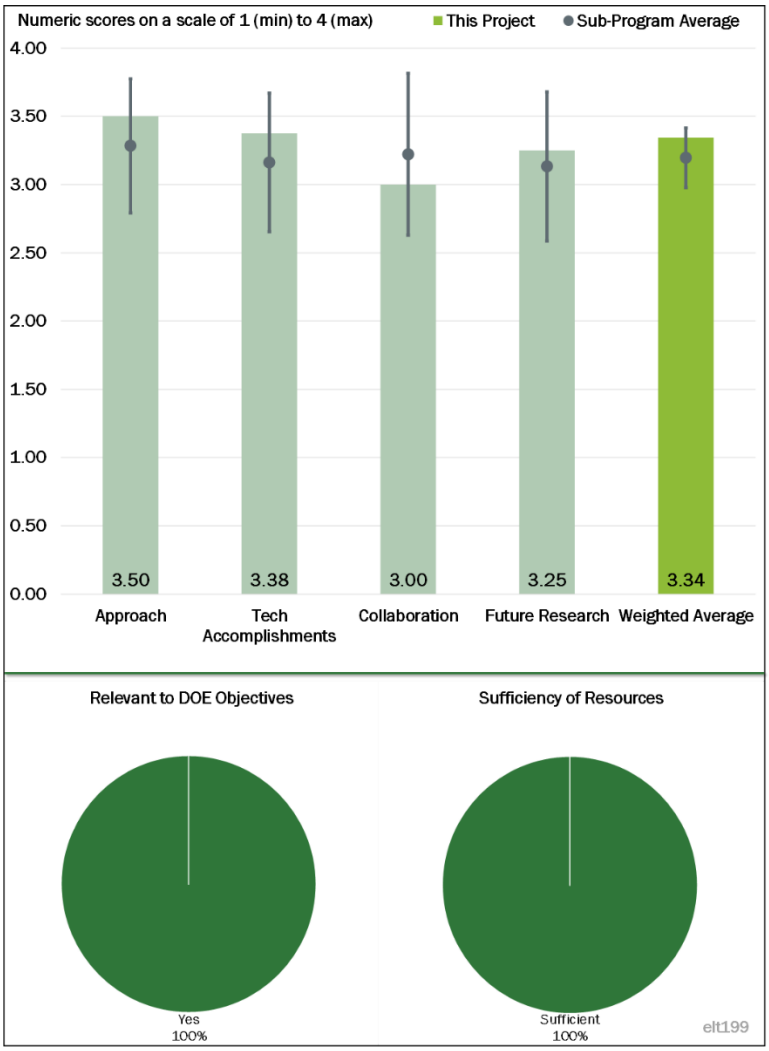

Figure 4-16 – Presentation Number: elt199 Presentation Title: Cybersecurity: Consequence-Driven Cybersecurity for High-Power Charging Infrastructure –INL Principal Investigator: Richard Carlson (Idaho National Laboratory)

Reviewer 1:
The reviewer stated that this is a new project and is in the early phase of deployment. The planned tasks are sensible and the initial task details reported will achieve the overall goals and objectives.

Reviewer 2:
The reviewer said this team took a logical approach to address the challenges on how to ensure/improve cybersecurity safety for high-power charging infrastructure. The approach starts with conceptualizing the events with high consequences, then prioritizing and analyzing these events based on impact and complexity. Lastly, the team will make recommendations on strategy and methods to address these events.

Reviewer 3:
The reviewer said the feasibility and effectiveness cannot be validated at this stage as no simulation/experimental results are provided. The technical barriers and challenges have not been discussed and so the contribution and effectiveness of the proposed approach is vague.

Reviewer 4:
This reviewer said that it appears the project team is working to define the scope of their project—what could go wrong, the consequences of it going wrong, if something goes wrong what is its severity compared to other events, and based on the severity work on the highest severity events in order of severity—highest to lowest. The reviewer said it looks like the scope of this project could become very large.

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

Reviewer 1:
The reviewer stated that the project is starting off with a definition of baseline potential cybersecurity threats and has defined the levels of magnitude and the overall threat assessment criteria. This work has been done very well, presents a comprehensive understanding of the subject matter, and should form the background to understand and define threats and ways to respond to them.

Reviewer 2:
The reviewer stated that this is the first budget period. The framework has been identified and a few events have been examplified. The team has completed the categorization of high consequence events (HCE) for high-power charge sites. The project appears to be progressing nicely.

Reviewer 3:
The reviewer said that the project team appears to have a plan for working on mitigation strategies based on the HCEs and finding solutions for their stakeholders.

Reviewer 4:
The reviewer said the presented accomplishments are minimal and not significant at this stage. Also, it seems that there are two different ranges for the HCE scores as per Slides 8 and 9, which are not consistent.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that strong collaborations with both the intellectual assets at DOE and the partners that can be affected by an attack have been shown. The cyber consortium is expected to bring specific real-world expertise to the project that would add significant value.

Reviewer 2:
This reviewer said the team is working with four other teams, trying to integrate all the efforts into one holistic effort, avoiding any repeating effort. The team used charging equipment from Tritium and ABB.

Reviewer 3:
This reviewer asked that when the project team talks about providing solutions to their partners, how they account for other utilities or infrastructure industries that may need the information they learned.

Reviewer 4:
The reviewer said the tasks, workload, level of involvements, and accomplishments of each collaborator need to be clearly and accurately mentioned, which is missing.

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 future tasks of this project seem to be well designed with a distinct roadmap of activities as well as a framework for performance to achieve the intended results. The initial work reported here has exhibited this.

Reviewer 2:
The reviewer said the proposed work on prioritized list of HCEs based on weighted impact severity and complexity, and from laboratory evaluation, appears to be logical. The proposed work on developing mitigation strategies and solutions is particularly important.

Reviewer 3:
The reviewer asked how the team will provide lessons learned to other stakeholders that are not part of the team. Otherwise the approach looks good.

Reviewer 4:
The reviewer said the proposed future research makes sense, but it is very broad with no technical details, which does not give the reviewer a clear idea of the proposed solutions.

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

Reviewer 1:
The reviewer said the objectives outlined here match well with the priorities of DOE and the real issues to be addressed.

Reviewer 2:
The reviewer said this work is critical for a safe EV charging infrastructure and is critical for defining other research efforts. This project's objective is to setup the framework for other researches on EV charging cybersecurity.

Reviewer 3:
This reviewer stated that cybersecurity is the serious threat that must be mitigated in all vehicle systems and the vehicle connections to the grid. When interconnected, neither the vehicle or the grid can provide a path for a cyber threat to cross the interface. This work can provide outstanding value on how to identify and potentially deal with these threats, if completed according to plan.

Reviewer 4:
The reviewer said that infrastructure must be safe and protected to avoid those HCEs. Safety first.

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

Reviewer 1:
The reviewer observed sufficient funding.

Reviewer 2:
The reviewer said the breadth of resources is correct for the program. The listed stakeholders must provide their portions of the work to bring about a favorable achievement of goals and objectives.

Reviewer 3:
The reviewer stated that this is just the start of the project, and the provided resources seem to be sufficient to support the execution of the project.

Reviewer 4:
The reviewer said that for their initial work the resources look sufficient. As the work progress the team may require more resources to help with infrastructure development to make all things safe in a timely manner. This will impact the design of the high power chargers being proposed.

Presentation Number: elt200
Presentation Title: Scalable Electric Vehicle Smart Charging Using Collaborative Autonomy
Principal Investigator: Steve Chapin & Jovanna Helms (Lawrence Livermore National Laboratory)

Presenter
Jovanna Helms & Steve Chapin, Lawrence Livermore 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 and well-planned.

Reviewer 1:
The reviewer said the plan and approach to this project is sound and well planned.

Reviewer 2:
This reviewer said this is a reasonable approach, given the limitations of data scarcity and demonstration difficulty.

Reviewer 3:
This reviewer noted the presenter stated the team is having some difficulty getting the charging network operators to cooperate because of proprietary information, etc. The reviewer suggested that including the utilities in the equation would help bring them to the table. The utilities would have a strong interest in maintaining the stability of the grid.

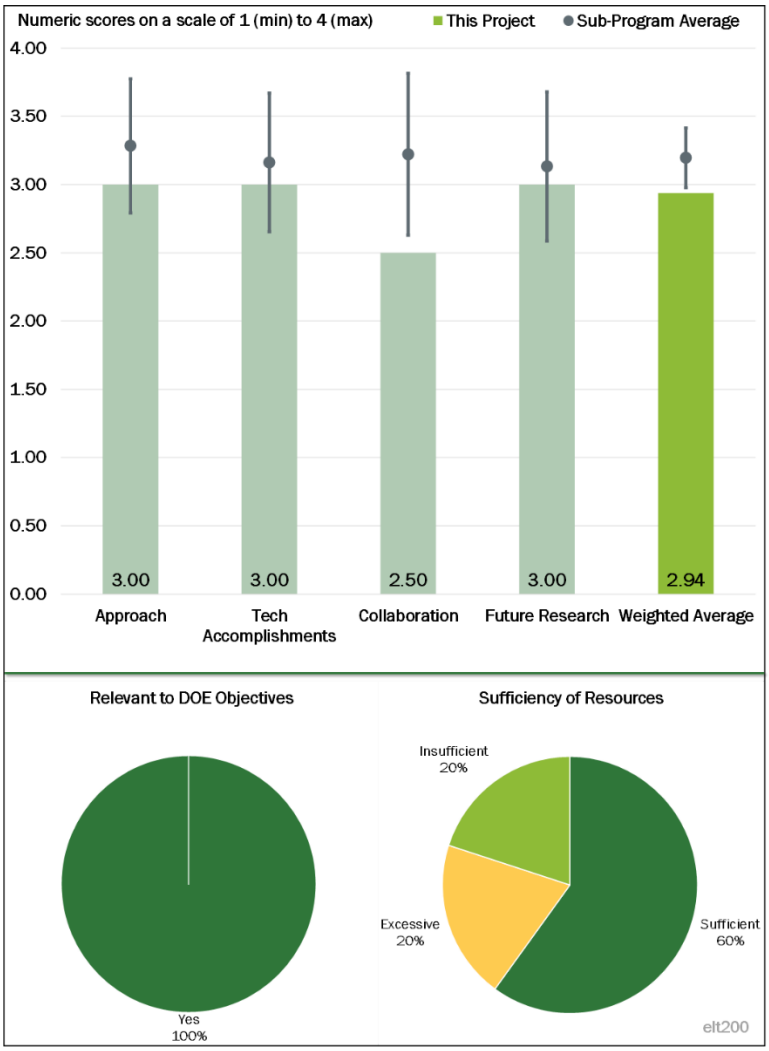

Figure 4-17 – Presentation Number: elt200 Presentation Title: Scalable Electric Vehicle Smart Charging Using Collaborative Autonomy Principal Investigator: Steve Chapin & Jovanna Helms (Lawrence Livermore National Laboratory)

Reviewer 4:
The reviewers said that overall, this was a great presentation and certainly an approach that needs to be investigated. The reviewer asked whether decentralizing charge management provides a more efficient solution to smart charging than the centralized approach. The reviewer did not see any mention of analysis being done to determine whether the decentralized approach would in-fact be more efficient than the centralized approach. Shifting the computing to decentralized devices would seem to yield a higher likelihood of failure—as you are now reliant on multiple computing devices, rather than one centralized computing device. The reviewer asked whether the benefit is worth the risk.

Reviewer 5:
The reviewer stated the proposed approach is very specific in developing software for distributed coordination of chargers. The approach did not include many limitations and practical issues such as: level of renewable energy generation (and so the change of generation and topology of the grid); benefits to EV owners; real-time pricing; and capacity of batteries. Also, it is not clear how practical this would be in a grid with thousands of PEVs as the load. It will work in a local area or feeder, but there is serious concern regarding validity on the grid. Therefore, the proposed work is only limited to software working in a specific situation and it is not scalable based on the current approach.

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

Reviewer 1:
This reviewer said the project is on track with excellent technical progress. Using "Skynet" as a moniker is tempting fate.

Reviewer 2:
The reviewer said the idea of decentralized implementation should ease the minds of the various charging network operators by allowing them to maintain a certain level of autonomy in their operations, while at the same time balancing the overall load on the grid—at least, much more so than having a centralized control over balancing the grid load.

Reviewer 3:
The reviewer stated that the progress to date has been adequate. The results of future work will demonstrate success or failure of the project.

Reviewer 4:
The reviewer said it seems that the project is mostly on task and on pace to hit its overall project targets. The only hiccup seems to be with finding partners to collaborate with in the industry. Hopefully this will prove to be a minor hiccup and will not delay the overall progress of the research.

Reviewer 5:
The reviewer stated that the presented technical accomplishments have not been validated through simulation/experimental studies. Using a hardware-in-the-loop (HIL) system for validation is tied to the limitations of the HIL system for both speed and the grid size.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said the project team has connected with all of the appropriate entities to complete the defined objectives.

Reviewer 2:
The reviewer said that at this point, it appears that only one charge network operator (ChargePoint) is on board. It would perhaps be helpful to get utility companies on board as well—perhaps leverage the contacts that some of the other labs have established in their previous work.

Reviewer 3:
The reviewer stated that most work for software development, and hardware-in-the-loop simulation and testing is done by LLNL as the project lead. ChargePoint, as the industry partner, provides the testbed and there is no other apparent coordination with other partners.

Reviewer 4:
The reviewer said there is currently only one other team member, so it is not ideal. There is a statement that the team is currently negotiating with others to supplement the team.

Reviewer 5:
The reviewer stated that this is where the project seems to be lacking a bit. It is a shame that ChargePoint is not a more active partner in this project, however, this reviewer was hopeful that the additional negotiations with other charging station vendors will yield to a strong partnership in the future. The innovative approach to demand response will certainly lead to some very interesting research findings. The reviewer hoped that there can be a strong partner in place to support the project from the charging station side.

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 next steps are well designed.

Reviewer 2:
This reviewer said that including HIL and not purely relying on simulation on the high performance computing (HPC) network is a good approach. The reviewer asked whether it has been decided that alternating direction method of multipliers (ADMM) is the best approach for optimization, or if there is any plan to explore alternate approaches to see if they provide a "more optimum" optimum solution.

Reviewer 3:
The reviewer stated that it seems the team has thoroughly planned their future research through 2020. The reviewer said it will be very interesting to see the project team's software being implemented on charging stations and working in the real world. Without a partner in place, it may be tough to meet these timelines, but hopefully the ongoing negotiations will get a hardware provider in place soon. This reviewer is very curious to see the advantages/disadvantages of the decentralized versus centralized approach to smart charging.

Reviewer 4:
The reviewer questioned whether the program will be successful without the support of EV charging network suppliers. The communication protocol and the execution speed are critical, and real hardware would be required to confirm that it works.

Reviewer 5:
The reviewer said that similar to the proposed approach, the future research is very limited with specific application. No plan is mentioned to specify how the project can be scaled.

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

Reviewer 1:
The reviewer stated that this project certainly supports the DOE's overall mission and objectives. This is the first such project of its kind that this reviewer is aware of. It seems that taking a decentralized approach to smart charging would yield itself to a safer grid—as it is likely to be less susceptible to cybersecurity attacks. This will undoubtedly help to bolster the robustness of our national grid and ensure safe and efficient power delivery for EVs in the United States.

Reviewer 2:
The reviewer said yes—it relates to the effect of higher EV adoption rates.

Reviewer 3:
The reviewer said this project investigates the importance of managing the charging of many EVs, which is important if EV adoption is widespread.

Reviewer 4:
The reviewer said the objectives outlined here match well with the priorities of DOE, if it is scalable.

Reviewer 5:
This reviewer believed that the project does, but questioned the project's viability if the charging network suppliers do not want to participate. It would seem that utility intervention would be required. Potentially, the team would have to develop standards and charging hardware requirements to make a significant impact.

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 sufficient, as of now.

Reviewer 2:
This reviewer said that progress is being made with available resources.

Reviewer 3:
This reviewer believed the $2.4 million budget for this project is sufficient, especially if a hardware partner is onboard to help shoulder to costs of developing the charging stations.

Reviewer 4:
The reviewer said that considering the project objectives and future research and plans, the allocated budget seems much more than enough.

Reviewer 5:
In this reviewer's opinion, without having charging hardware to test with, this project will not demonstrate the objectives.

Presentation Number: elt201
Presentation Title: Charging Infrastructure Technologies: Smart Vehicle-Grid Integration—ANL
Principal Investigator: Keith Hardy (Argonne National Laboratory)

Presenter
Keith Hardy, 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 and well-planned.

Reviewer 1:
The reviewer noted that this project aims to involve many partners and moving parts. Excellent approach to getting the work done.

Reviewer 2:
The reviewer said the Energy Plaza concept is well designed. However, little information is presented on resiliency studies. The reviewer asked if case studies for situations of high power demand, for example weather events, will be addressed in this study.

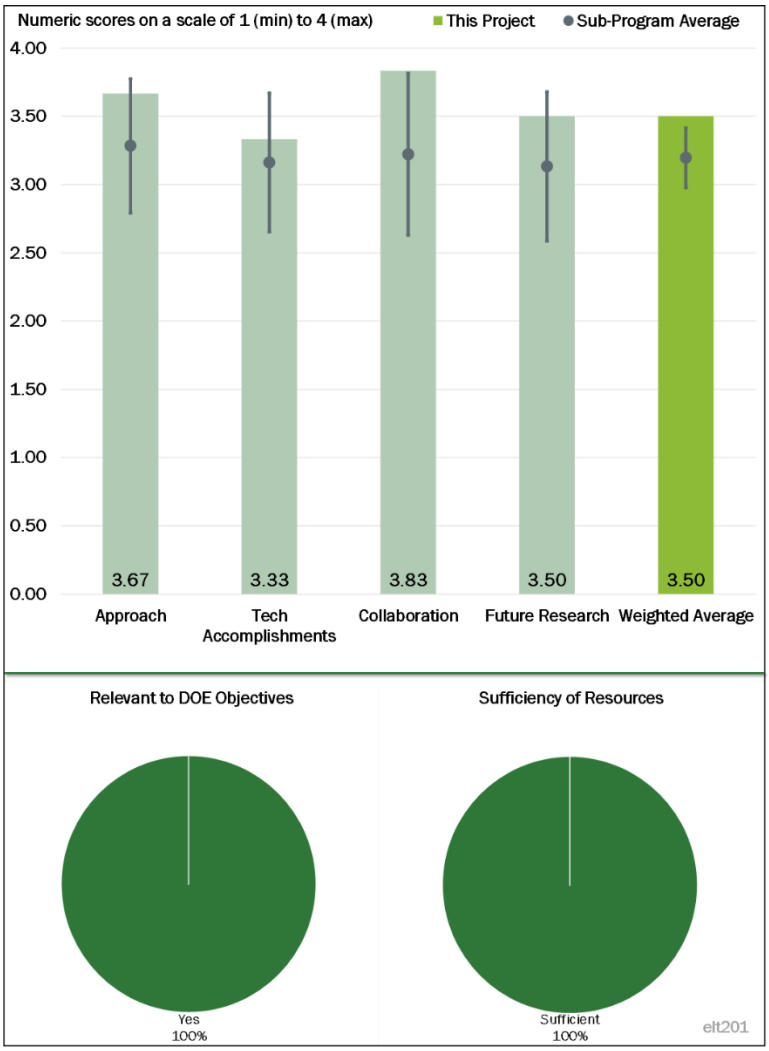

Figure 4-18 – Presentation Number: elt201 Presentation Title: Charging Infrastructure Technologies: Smart Vehicle-Grid Integration—ANL Principal Investigator: Keith Hardy (Argonne National Laboratory)

Reviewer 3:
The reviewer commented that the PI did a great job explaining the challenges that are being faced in commercializing the research. It would have been nice to hear a bit more on the challenges that are faced from an OEM hardware perspective. For example, in order to commercialize vehicle-grid integration (VGI), what sort of hardware changes are needed from the OEM side (low latency). Otherwise, the presentation was great and addressed the fact that there is still no consensus on the communication protocols.

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

Reviewer 1:
The reviewer noted that the Task 1 Milestones were completed ahead of schedule.

Reviewer 2:
This reviewer said the progress is comprehensive and in several directions. The reviewer asked three questions: whether cybersecurity concerns will be addressed in this project; what the desirable characteristics

are of smart charger adapters; and what is needed to develop the consensus of EVSEs to harmonize adapter characteristics.

Reviewer 3:
The reviewer said it was exciting to see how far along this project has come, especially with the creation of the smart energy plaza. However, the reviewer said it was somewhat disheartening to hear that after so many years of research, we are still 2-3 years away from a lab demo and 4-5 years away from a public pilot. The reviewer is sure this is mostly out of the control of researchers, but said it would be nice to see a quicker turnaround for a public pilot of the technology. The reviewer said the smart charge adaptor is a great idea, and hoped that this is able to come to market as an enabler to older EVs that will not have smart charging technology.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said there is no question here that the collaboration and coordination on this research is outstanding. The team has been able to gather key industry stakeholders from OEMs to energy suppliers and utilities. All of the important players are being included on this project, and this reviewer is sure the outcome of the research will reflect as such.

Reviewer 2:
The reviewer commented this very large group of collaborators is being managed well, with clearly defined roles and responsibilities.

Reviewer 3:
The reviewer noted that U.S. and European Union industries are mentioned in collaboration. The reviewer also suggested collaborating with China, where development is rapid.

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 it seems the team has been very forward thinking in terms of their future research plans. The smart charge adapter sounds like a great tool to utilize all of the existing EVs that are on the market today. The determination of future strategies for grid services will prove crucial as well, and the reviewer hoped that the team can come up with new ideas to support the grid with smart charging EVs at scale.

Reviewer 2:
This reviewer said the next steps are logical. The reviewer noted that one step depends on future availability of standards-compliant EVSE equipment. The reviewer asked if this is known with certainty.

Reviewer 3:
The reviewer said the plan presented addresses several very important aspects of the project. The reviewer asked what additional hardware equipment will be required and how will they be applied. The reviewer stated that grid resiliency and reliability are different concepts, and asked how they are quantified.

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

Reviewer 1:
This reviewer said the project seems crucial to the overall mission and objectives of the DOE. In order to ensure that we have a strong, reliable, and robust electric grid, we must ensure that the biggest consumers on the grid (EVs) are smart and efficient in their energy usage.

Reviewer 2:
This reviewer said the project work is important in reducing the "friction" of EV adoption by enhancing equipment interoperability and promoting optimal charging operations

Reviewer 3:
The reviewer stated that the scope of this project is significant with respect to DOE objectives. Smart interoperability, communication, smart charging equipment, and pricing dynamics are involved. The EV plaza and its improvements provide an excellent test bed.

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 appear to be adequate based on progress.

Reviewer 2:
This reviewer noted that it is not well understood what additional hardware is required to finish the project. Therefore, the reviewer cannot comment on the financial resource question. However, the project team has chosen the right human resources and collaborators.

Reviewer 3:
This reviewer said the budget of about $3 million/year for this project seems a bit high given that the project is still several years away from a commercial pilot. It would be nice to see industry stakeholders shoulder a larger portion of the budget to get more skin in the game and hopefully bring the technology to market sooner.

Presentation Number: elt202
Presentation Title: Charging Infrastructure Technologies: Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE)—NREL
Principal Investigator: Kevin Walkowicz (National Renewable Energy Laboratory)

Presenter
Kevin Walkowicz, National Renewable Energy 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 and well-planned.

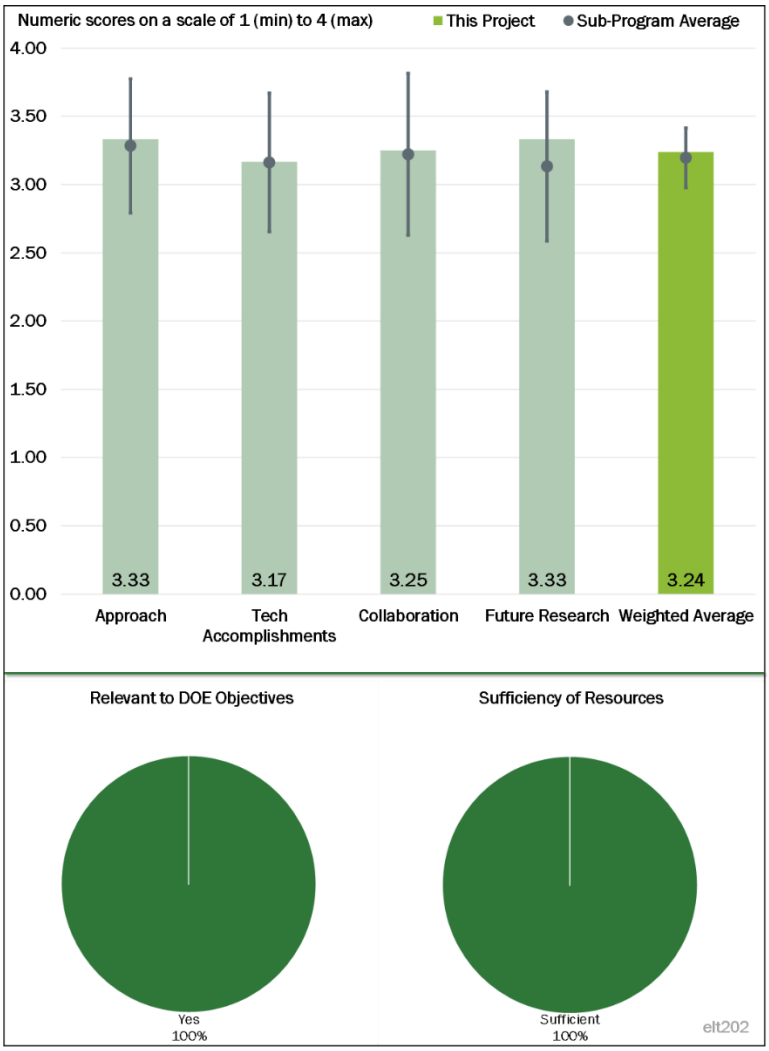

Figure 4-19 – Presentation Number: elt202 Presentation Title: Charging Infrastructure Technologies: Smart Electric Vehicle Charging for a Reliable and Resilient Grid (RECHARGE)—NREL Principal Investigator: Kevin Walkowicz (National Renewable Energy Laboratory)

Reviewer 1:
The reviewer stated that this project is collecting data from unmanaged charging followed by collection of data from managed charging. Then it will use the data from unmanaged and managed charging to carry out co-simulation, which consists of PEVs and grid from two major regions in the United States. The data available from co-simulation can become the basis for advanced charging strategies. It is anticipated that the outcome of this project could relieve and reduce peak loading on the electric grid. This reviewer felt that this project is using a rational, practical, and data driven approach to emulate uncontrolled and controlled behavior demonstrated by EV owners, and then discipline their behavior by appropriate incentives and tariffs to relieve the electric grid under the onslaught of unknown peak loads posed by fast charging stations. It is likely—if findings of this project are adopted by owners of charging stations, EVs and electric utilities—that the electric grid could be made reliable and resilient.

Reviewer 2:
The reviewer said this project has taken a broader view of the challenges of charging and is excellently designed from that perspective. By addressing two different geographical locations, the project has also broadened the applicability. The reviewer remarked it would be a good addition, however, if this also could address an urban versus semi-urban difference. This will also take into account the charging needs of an autonomous taxi fleet, as opposed to only near term EV adoption. Such a fleet will impact the load on the grid and may challenge a model made only from the residential charging input.

Reviewer 3:
This reviewer remarked that the PI did a great job explaining the background of the research and the barriers that could be faced. The reviewer wanted to see some discussion on how localized renewables would play a role in the data that are being gathered. Additionally, given that the research is taking place in Minneapolis and Atlanta, the reviewer asked what sort of extrapolation could be expected in a more rural setting.

Reviewer 4:
The reviewer said that this project addresses an important aspect of larger scale EV adoption. The reviewer offered two observations: a) The reviewer is not sure it makes sense to use "uncontrolled" charging as the baseline scenario. The charging infrastructure companies will likely have some mechanism to prevent significant impact on the grid quality metrics, even if it is just to protect their own investment. That would be a more viable baseline scenario. The comparison should be between that, and coming up with what would be an optimum charging scenario, and how that would improve the grid performance metrics, and how far that would take us without significant grid upgrades; and b) It would also seem that if we assume significant penetration of EVs, then grid infrastructure upgrades would be unavoidable (Slide 3, bullet 3)

Reviewer 5:
The reviewer said the approach looks very much the same as the previous many researches. Therefore, the approach is okay.

Reviewer 6:
The reviewer said the overall approach of the work that is on-going seems sound, but suggested possibly re-framing some of the motivation slightly. One of the main reasons to pursue electrification is carbon dioxide (CO_2) reduction (or at least it has the perception), so this work should be used to help try and answer how much CO_2 reduction/gain is associated with electrification of automobiles. Because CO_2 production moves heavily to the power producers for electrified vehicles (xEVs), from individual vehicles with internal combustion (IC) powertrains, it would be good to at least partially address this issue with all of the data you are generating. A second topic that this reviewer offered for consideration is determining whether there is a problem with the grid in the first place. Basically, motivate the reasoning for this work a little bit better. For example, the reviewer asked whether there would even be an issue with the grid if the project team just let things go relatively unplanned. The team's results on one of the slides showed something like one or two "under voltage" points, which seemed like a small percentage to this reviewer. Of course, this is a really limited sample size, but maybe it suggests minimal problems would be seen without significant planning effort. Another comment the reviewer provided is to consider customer needs and behaviors much more closely. For example, suppose the average customer does not want limited charging capacity during the day (or whenever they do the bulk of their driving), but they may accept it at night. The last comment is to probably have some sort of estimate of the number of charging stations needed based on uptake rate of xEVs. They charge a lot longer than gasoline vehicles, so you might expect there to need to be many times more charging stations than gas pumps (home charging limits this though).

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

Reviewer 1:
The reviewer said the research is still in the very early stages, so it is understandable that the technical accomplishments and progress are not completely there yet. However, the data that have been gathered thus far were impressive.

Reviewer 2:
The reviewer stated that the accomplishments are limited but this is understandable, as the project just started half a year ago. This reviewer looked forward to more results for the year 1 milestone review.

Reviewer 3:
The reviewer suggested a few other things that could be interesting at which to look. First, other countries in the world already have significant EV penetration (Norway and Iceland come to mind). In fact, Iceland is considering cutting down the number of gas stations in Reykjavik by half. It would be good to have a conversation with these countries (or the government entities with similar responsibilities in those countries) and see how they are handling similar issues that they have presumably faced already. Second, the presentation makes some assumptions (Slide 12, for instance) on the number of Level 1 and Level 2 charging stations required/available. If we start with the assumption that the number of gas stations that we have in most parts of the United States have adequate capacity to serve the number of registered automobiles in the surrounding area, it would then be interesting to see how the assumptions on the number of charging facilities would compare, after taking into account (in some fashion), the convenience, the charging rates, etc.

Reviewer 4:
This reviewer stated that it seems like the technical progress has been effective so far, and good results have been obtained. The team may just want to more closely investigate and include charging behavior of humans. It might also be good to quantify the influence of the team's assumptions (through some sort of sensitivity analysis) because this can also lead to important findings as to what should be the primary considerations for charging infrastructure design.

Reviewer 5:
The reviewer stated that the overall progress is good, however, a deeper dive into data is needed. There is not enough actual data at this point and the project will need to catch up on this with most of the data expected to come in the next few months or next year. The reviewer noted that access to data is limited as this point, so perhaps more focus can be brought to this for next year's review.

Reviewer 6:
The reviewer noted that non-disclosure agreements (NDAs) are in place and feeder locations are identified. If the project does not progress as per plan, it would be a good idea to have an exit strategy in place.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that this is outstanding. The team has really reached out to all the correct stakeholders.

Reviewer 2:
The reviewer highlighted the great job that the PI did in establishing collaboration across both research entities and commercial industries. The inclusion of Southern Company will no doubt offer them the industry support the team needs in Atlanta.

Reviewer 3:
This reviewer said the project team has a good division of labor between the various National Laboratories, it appears that Xcel Energy is already sharing data from the Twin Cities, and the data from Atlanta should be forthcoming after the NDA with Southern Company has been executed. More international cooperation with regions of the world which have already experienced similar issues may help advance this project quicker.

Reviewer 4:
This reviewer stated that multiple DOE labs and two major utilities are involved as collaborators in the NREL-led project.

Reviewer 5:
The reviewer said that collaboration seems good so far, but suggested trying to get much more input from the power producers. For example, the way that power companies determine power producing capacity for a given

day (usually a day in advance) may have an influence on which projects you choose to pursue. Accurate next-day predictions of usage are pretty important to cost and CO_2 reduction for power production.

Reviewer 6:
This reviewer said that collaboration for this project is interesting, and it is difficult to convince the reviewer that grid impact analysis for two different cities have to be done by two different teams in two different locations. It seems to the reviewer that it should be more reasonable for one team to handle both example cities, so that all the comparisons and optimization can be fairly compared.

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 said that a great future research plan with multiple tasks has been identified by the project team and described by the project presenter.

Reviewer 2:
The reviewer said the project has a very good outline and is focused on the task on hand. As stated in the project presentation, the bulk of the data are expected to come through various agreements and the plan for utilizing these data is very well laid out.

Reviewer 3:
The reviewer said the plans for future research in 2020 and 2021 seem solid and will certainly help to reinforce the data that are gathered in 2019. It will be interesting to see if other utilities opt to use the tools created from the research in their own market area.

Reviewer 4:
The reviewer stated that the future directions seem reasonable, but the reviewer would seek input from power producers and xEV owners to help shape assumptions and project tasks.

Reviewer 5:
The reviewer said this is an overall good plan, but please take a look at what others have done already.

Reviewer 6:
The reviewer stated that the proposed future research looks well-planned. However, the project claims to provide solutions to increase the value for PEV owners, building managers, and so on. This value is kind of vague, and it would be nice to address specifically in the future research plan what kind of value is going to be addressed.

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

Reviewer 1:
The reviewer said yes, this project is highly relevant to the DOE objectives. We need to understand and avoid the negative grid impacts for large scale PEV penetration, and also provide solutions to increase the value for PEV owners, building managers, and so on.

Reviewer 2:
The reviewer said yes, EV penetration is partially limited by infrastructure—so these types of studies are very important. Additionally, if xEV penetration exceeds grid capacity it may become a huge issue for the owners of those vehicles and the perception of xEVs by the public. xEVs are also improving energy security because most fuel sources are domestically sourced.

Reviewer 3:
This reviewer said the project is very relevant, and the outcome of the study carried out in the project could be very helpful for deep and rapid penetration of EVs in the United States. As an eventual outcome of this project, EV owners may be less worried/concerned about charging of their vehicles, including the cost of electricity.

Reviewer 4:
The reviewer stated that the project does support a key and very urgent objective of power management as EV adoption breaks through a critical barrier of adoption. This is expected to happen sooner rather than later, and this project is very timely to address many upcoming issues.

Reviewer 5:
This reviewer said that large scale adoption of EVs will bring up questions about grid interaction and stability, and this is definitely something that should be investigated.

Reviewer 6:
The reviewer said this project is very relevant to the DOE's overall mission and objectives. As one of the reviewers mentioned, it seems that Norway and other countries are already be ahead of us on a per capita basis of EV sales. It is important for DOE and utilities to be aware of how these vehicles will affect the long-term viability of the energy grid. The research will also help to shed light on potential weaknesses with our current grid.

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

Reviewer 1:
The reviewer said that the project has a great team consisting of multiple DOE National Laboratories and two major utilities. The simulation tools have been identified and are in place.

Reviewer 2:
The reviewer said the resources seem to be sufficient. The team contains enough National Laboratory experts, and the data are supported by the utility companies.

Reviewer 3:
This reviewer stated that the funding seems sufficient to cover the scope of this project. Additionally, the manpower support from the various labs makes the reviewer confident that the project should be able to hit its milestones and succeed in gathering the required data.

Reviewer 4:
The reviewer commented resources are sufficient.

Reviewer 5:
The reviewer said the funding seems sufficient to meet the project objectives.

Reviewer 6:
The reviewer stated that the resources appear significant at this time.

Presentation Number: elt204 Presentation Title: Charging Infrastructure Technologies: Development of a Multiport, ≥1 MW Charging System for Medium- and Heavy-Duty Electric Vehicles—NREL Principal Investigator: Kevin Walkowicz (National Renewable Energy Laboratory)

Presenter
Kevin Walkowicz, 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 and well-planned.

Reviewer 1:
This reviewer said the three pronged approach spread over three performance years looks reasonable for a successful execution of this project

Reviewer 2:
The reviewer stated this project has addressed and outlined all the important barriers to adoption. It seems a little bit challenging at times given the breadth of the scope—from logistics to material selection.

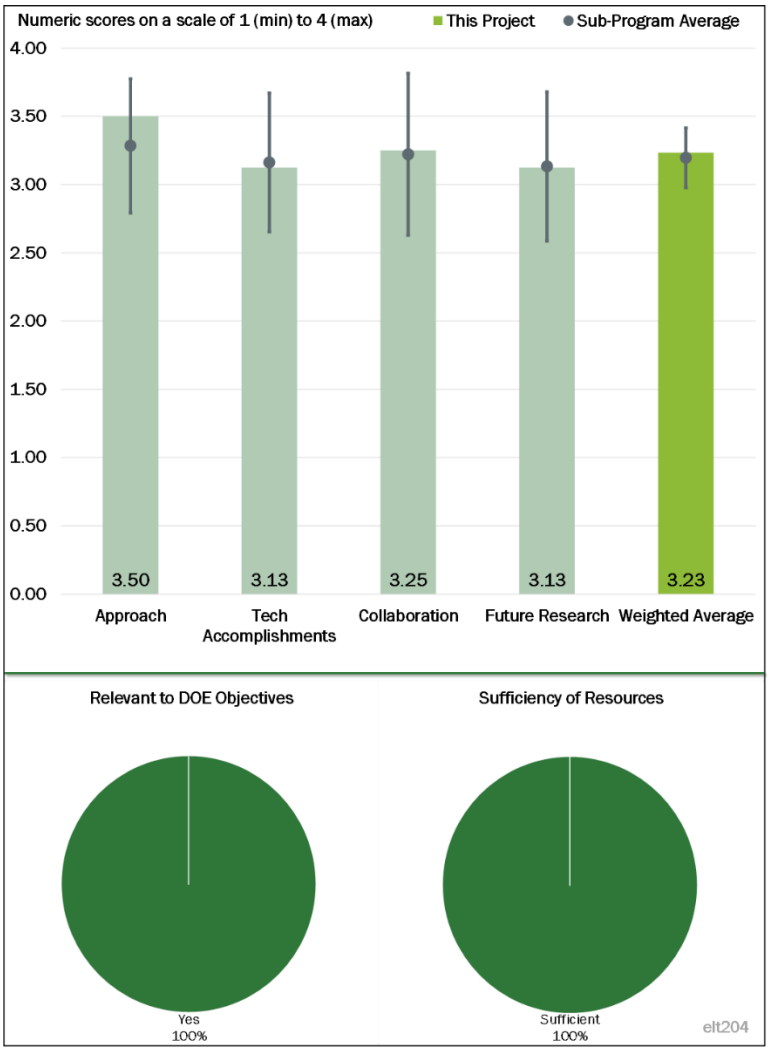

Figure 4-20 – Presentation Number: elt204 Presentation Title: Charging Infrastructure Technologies: Development of a Multiport, ≥1 MW Charging System for Medium- and Heavy-Duty Electric Vehicles—NREL Principal Investigator: Kevin Walkowicz (National Renewable Energy Laboratory)

Reviewer 3:
This reviewer said that using data from 991 Class 8 trucks gives a fairly large-sized data set to start from, to look at likely charging profiles. A couple of other things that may be helpful would be to look at the current number and distribution of gas stations serving Class 8 trucks. Perhaps this could be normalized in some manner (in terms of rate of fuel flow/charge rate, number of gas pumps/truck) and compared with the proposed number of charging stations to see if they are in the same ball park. The idea of minimizing cost by maximizing utilization of charging stations is good, but the minimum solution may not help with the adoption of EV trucks. There will likely have to be a slight overcapacity to ensure that the system works smoothly. In addition, having an overcapacity (not more charging ports at each station, but having more charging stations along the routes) may also improve the grid quality metrics.

Reviewer 4:
This reviewer recognized that this project is just beginning, and the project plan does exist. It appears robust, but the reviewer believed a review of the deliverables might make it more robust. Meaning this project might benefit from a re-plan 1 year in.

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

Reviewer 1:
This reviewer noted that quite a bit progress has been made, which is evidenced by "analysis tools have been developed to assess and estimate long-haul trucking energy demands. Preliminary optimization has been carried out for maximum utilization of charging station with minimal cost spend for identified route of electrified vehicle. Load profile for electricity uses being carried out."

Reviewer 2:
This reviewer seemed to recall hearing that New York City (at the 2019 CTI Symposium in Novi, Michigan) is planning to install 1 MW+ chargers for electric buses. A discussion with the appropriate authorities in New York City may be helpful in understanding what problems they are facing in implementing a 1MW+ fast charger. Also, this reviewer asked if there are any 1MW+ chargers that have been installed anywhere in the world. The presentation does not make any such reference, but if there, it would make sense to first understand what kind of issues these charging stations are facing.

Reviewer 3:
This reviewer said there are not many accomplishments to highlight yet. Progressing a plan and identifying who works on what has been completed.

Reviewer 4:
The reviewer noted that this project still seems to be using lot of auxiliary data, and the data source is not very clear in the presentation. More details are needed on the thermal simulation data. The reviewer inquired about the following: the actual temperature profile of the pin; the highest temperature of the connecter; and the highest temperature and lifetime that will be needed to implement materials selection and lifetime reliability. The reviewer said the project needs to show sensitivity of the charge location to various input components such as range, and asked that a parameter sensitivity component for model robustness please be included.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
No complaints were stated by this reviewer.

Reviewer 2:
The reviewer noted that three DOE labs are working together

Reviewer 3:
This reviewer said the project is well connected and has all the right elements. However, the industry collaborations are not very clear despite having a very long list of potential partners. The reviewer asked who is supporting and doing what.

Reviewer 4:
This reviewer believed that engaging more stakeholders earlier rather than later will really help this project. Maybe a truck stop operator, or fleets who exclusively use truck stops, others such as Nikola and Tesla who are working not only on fast charging and fueling, but on infrastructure in creating new truck stop models. The project team could also collaborate with other industry groups that represent truckers who use these facilities. The reviewer said that trucking is moving a bit toward more regional operations, and asked how this will affect the plans and analyses of 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:
This reviewer stated that project tasks for future research have been identified and stated in the annual report such as complete the simulation of medium-voltage architecture; finalize station load profiles; complete the grid impact analysis with refined distribution feeder information; complete model-based charge control; continuation of charging connector research; and publication of draft report that includes information/data on industry interactions.

Reviewer 2:
The reviewer said there is a great deal of developments in this scope and a scheduled re-plan of future research might be prudent.

Reviewer 3:
This reviewer said that hardware selection must be brought up in the timeline because we are talking about extremely fast charging, therefore a quick hardware feasibility check will keep it grounded.

Reviewer 4:
This reviewer said that 1.2MW @ 85% efficiency gives 180 kW of heat! That is a lot of heat and it seems like (barring costs) a strong case could be made for waste heat recovery. Secondly, a single 1MW+ charger at 480 volts (V)gives about 2000 A current. Ten such charging ports require 20 kA current. The reviewer asked whether it would make sense to look at higher voltage power electronic topologies. This would also result in an increased efficiency (with lower I^2R losses) and perhaps obviate the need for waste heat recovery. In other words, the reviewer asked if the review of power electronics topologies should be limited to 480V systems.

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

Reviewer 1:
The reviewer stated that this project supports the DOE objective of automotive electrification and its impact on energy sources.

Reviewer 2:
The reviewer said yes, because multi-megawatts charging stations distributed across the route of EVs could spear rapid adoption of clean transportation technologies.

Reviewer 3:
The reviewer said that this is needed to improve adoption of EV trucks.

Reviewer 4:
This reviewer said that charging is critical to taking advantage of the plethora of benefits that come with electric trucks.

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 it seems sufficient.

Reviewer 2:
This reviewer said resources look good.

Reviewer 3:

This reviewer stated that experts from three DOE National Laboratories with means to collect data, and analysis on the collected data, will be quite useful for successful execution of this project.

Reviewer 4:

The reviewer said that currently the project has sufficient resources. However, the project scope is pretty wide and may need further support in the future once all industry participation takes off.

Presentation Number: elt205
Presentation Title: Cybersecurity for Grid Connected eXtreme Fast Charging (XFC) Station (CyberX)
Principal Investigator: Junho Hong (ABB)

Presenter
Junho Hong, ABB

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 and well-planned.

Reviewer 1:
This reviewer stated that it is a good approach because this project involves all possible stakeholders.

Reviewer 2:
The reviewer said that while the need of the cyber secure XFC) is clear, the approach to a secure station is only vaguely defined. Not much information was shared at the Annual Merit Review (AMR).

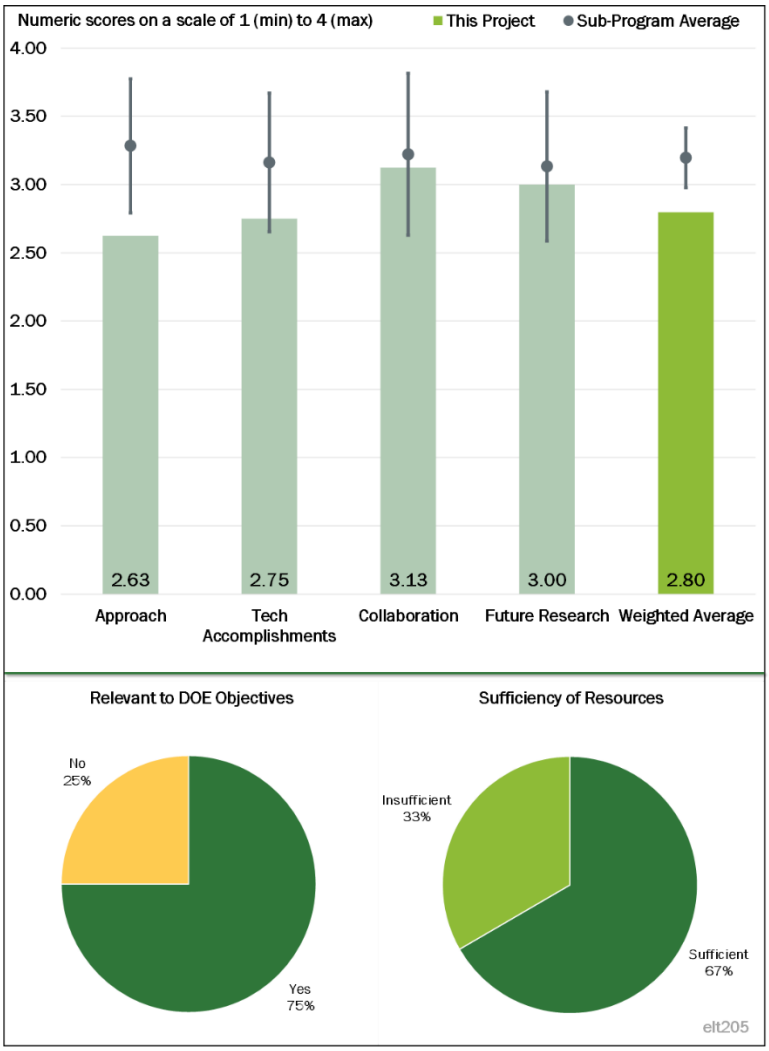

Figure 4-21 – Presentation Number: elt205 Presentation Title: Cybersecurity for Grid Connected eXtreme Fast Charging (XFC) Station (CyberX) Principal Investigator: Junho Hong (ABB)

Reviewer 3:
This reviewer said it was not clear from the presentation that a probability of risk and consequence analysis was being done with the threat analysis at the same time, but was addressed in the question and answer session. Also, a vulnerability analysis should have been done at the same time as the threat analysis. Most important is that the analysis of anomalies, their probabilities and their consequences should have been done at the same time (concurrent with the threat analysis). The reviewer remarked it is NOT clear how a design for detecting anomalies and threats can be done without knowing both and establishing the criteria for differentiating between them. Also, it is not clear that a literature search and analysis was performed to determine what standards and best practices are available to take advantage of in this project.

Reviewer 4:
The reviewer noted that this is a new project started in January 2019. The team did not provide detailed information for the possible cybersecurity attacks to charging station. This reviewer agreed that this is a concern, but the project report did not provide more information than what the reviewer can get from CNN news as an engineer. The team did not provide any information about the type of cybersecurity that may exist for XFC station, and how the team will detect and mitigate such serious issues. The reviewer is not sure the team will simply build a XFC station, run it, and see if they can find any possible issues associated with

cybersecurity, or they know the cybersecurity issues and will develop methodology to detect and stop the possible attack to XFC stations.

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

Reviewer 1:
This reviewer noted that the project is only 20% complete and 25% of the time is taken up. Because of the large number of stakeholders, it is not possible that more time than allocated is needed to fulfill the objectives satisfactorily.

Reviewer 2:
This reviewer said the project just started in January 2019, so the reviewer cannot expect a lot.

Reviewer 3:
The reviewer noted that this is a new project. It is difficult to justify the technical accomplishments based on the information provided. Plus, it may be not fair for this team to provide the detailed progress report in such a short period.

Reviewer 4:
This reviewer stated that while a good 20 minutes were used to describe the project and the progress at a high level, it seems little information is shown. The reviewer wished the team had shown more specific information on station system layout and on use cases.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said the coordination with stakeholders is excellent.

Reviewer 2:
The reviewer said the ABB team does work closely with the INL team, and each team's role is clearly defined.

Reviewer 3:
This reviewer said the project involves numerous partners. According to the research team communication plan, the team members should be able to collaborate well.

Reviewer 4:
The reviewer said there should have been more collaboration with the end-users. The principal investigator should or would have learned that primary threat against trucks is not denial of service or sabotage for fun, but cargo theft or use of hazardous materials as a weapon. Especially, the most targeted cargo for theft is electronics—where the technology being developed by this project would be most useful. An end-use analysis should have been conducted for this project to determine how much electric trucks in Class 6 carrying such cargo would benefit from the technology being developed by 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 that the research team provided an overall approach in Slide 6 that seems to make logical sense.

Reviewer 2:
This reviewer did not see any go/no-go decision points, and that is the only issue. The project is based on building on tasks performed in logical sequence—so without decision points, the grantee can be given carte blanche to proceed at risk to the government.

Reviewer 3:
The reviewer pointed out that clear objectives and responsibilities of what to be included in the proposed standards were not apparent. The reviewer asked the following: whether stakeholders will propose the items in the standards document; by whom and how the standards will be approved; and whom in the Federal government will the Electric Power Research Institute (EPRI) approach with the standards document, post project completion.

Reviewer 4:
The reviewer said that while the proposed research is outlined, it is vague in describing the challenge, the rationale, and the approach of the new research.

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

Reviewer 1:
This reviewer said that standards will greatly facilitate the automotive industry and the adoption of EVs. This project addresses that.

Reviewer 2:
The reviewer said a 350 kW XFC will become one of the major components for grid infrastructure. A cyber secure XFC station is absolutely needed for a secure and efficient energy economy.

Reviewer 3:
The reviewer stated that the project is relevant to DOE objectives in promoting EV application in the United States. Cybersecurity is very important in fast charge stations. However, the reviewer is not clear if the research team has clear ideas about the safety issues associated with the design and operation of the charging station and the cyber-attacks from external sources. The research team should have these issues addressed. Otherwise, DOE may be funding a safety project under the cybersecurity umbrella.

Reviewer 4:
The reviewer said there was no information on Slide 4, "Relevance," justifying the relevance of this project to overall DOE goals and 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 said that funding should be sufficient for this team to complete the research work proposed.

Reviewer 2:
The reviewer said this project is well funded for the proposed objectives.

Reviewer 3:
This reviewer said that time is perhaps not sufficient to finish the objectives with such a large number of stakeholders.

Presentation Number: elt206
Presentation Title: Cybersecurity Platform and Certification Framework Development for XFC-Integrated Charging Infrastructure Ecosystem
Principal Investigator: Tobias Whitney (Electric Power Research Institute)

Presenter
Tobias Whitney, Electric Power Research Institute

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 and well-planned.

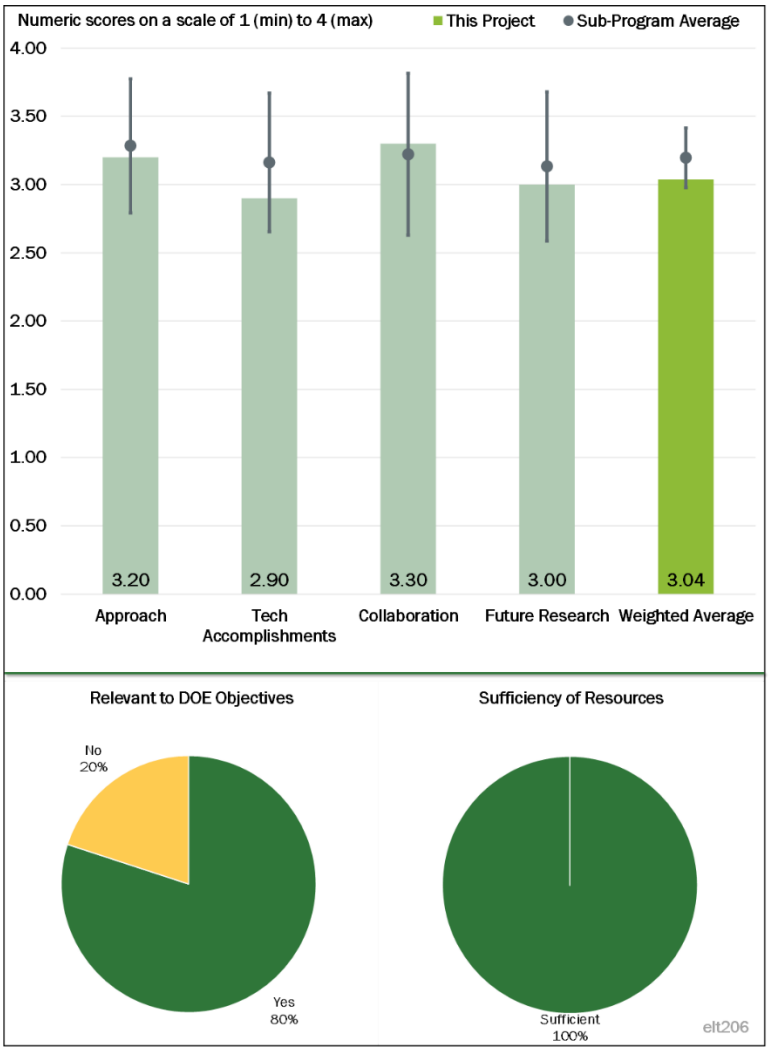

Figure 4-22 – Presentation Number: elt206 Presentation Title: Cybersecurity Platform and Certification Framework Development for XFC-Integrated Charging Infrastructure Ecosystem Principal Investigator: Tobias Whitney (Electric Power Research Institute)

Reviewer 1:
The reviewer said this project has a very well-developed structure designed to result in gaining the knowledge necessary in this area and disseminating that information, gained through coordination with industry stakeholders through the working group activity. The working group structure includes many of the exact types of organizations critical to moving forward, and will hopefully become a sustaining activity after this project ends. Thus, this appears to be exactly the needed approach to move toward standards and requirements in this area. In addition, the project is taking advantage of key laboratory capabilities to answer specific questions, leveraging highly effectively. The project is also taking specific care to create a variety of reporting mechanisms/tools for different uses and users.

Reviewer 2:
The reviewer remarked that engaging as many different stake holders as EPRI has done is a great start. The milestones and tasks are clearly laid out, but the reviewer was curious about the fairly aggressive timeline. With so many stakeholders involved, the reviewer inquired about the meeting schedule to help achieve all the deliverables, and asked what would happen if there are conflicting demands from the various stakeholders.

Reviewer 3:
The approach seemed sound to this reviewer. The reviewer liked the logical, coherent breakdown of the cybersecurity for extra fast charging into three architectural scenarios: (i) EVSE - system, (ii) EVSE - vehicle, and (iii) EVSE - cloud with milestones for each scenario. The only task missing is a literature search to

compile a roster of prevailing standards and best practices and an analysis of what new standards and best practices are needed.

Reviewer 4:
The project was laid out simply enough and should begin to align the many partners in this space with common goals to provide a level of uniform protection and secure operation; however, it seemed to be insensitive to the work that have already been done in this area for ecommerce protection and the historical experiences/knowledge/procedures that it may provide.

Reviewer 5:
The reviewer noted that an 1 XFC and remainder by the model is proposed. The reviewer asked what the drawbacks are of not having full hardware set versus. model-based analysis. The reviewer asked what the causes are of false positive and false negative anomalies, and what the frequency is of such wrongly detected anomalies.

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

Reviewer 1:
The reviewer said that so far, the project appears to be making very good progress. As with other projects in this area, this team started with development of a risk matrix, but in this case, it was based upon the particular perspectives of industry. Then it moved onto creating the industry-based working group. The project started relatively recently, so more will be accomplished over the next few months.

Reviewer 2:
The reviewer stated that this project has been underway for a relatively short time, but reasonable progress appears to have been made.

Reviewer 3:
This reviewer said the technical accomplishment is adequate.

Reviewer 4:
This reviewer said that given the large number of partners associated with this project, though many are through the working group, there was good progress in developing the various risk matrices. It would be beneficial however, to show how these were vetted outside of the working group to ensure that no items were missed.

Reviewer 5:
The reviewer noted that the project started in October 2018 and ends in December 2020, yet it is only 5% completed. The grantee has just over 17 months to perform the remaining 95% of the work.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said the project team has done an excellent job of bringing together multiple OEMs, utility companies, and other parties. It is also good to see that two of the National Laboratories are also involved.

Reviewer 2:
The reviewer said there is terrific collaboration for this project. Not only does the team itself have many of the critical types of partners, but they have created larger working groups with a broad range of industry stakeholders. This will be critical for moving toward standards and requirements. The project has also set up communication with exactly the types of organizations critical for successful dissemination. While the team appears to have not seen major impediments to getting industry to join the working group, the principal

investigator clearly understands that effort is needed to keep the industry members contributing effectively and sharing to the level needed for progress to occur. There is only one short-coming—the team could probably use some involvement of the U.S. Department of Transportation (DOT) to ensure coordination with future DOT plans.

Reviewer 3:
No specific comments were stated by this reviewer.

Reviewer 4:
The reviewer said the project team had a large number of collaborators and seemed to be utilizing them well, though the lack of integration with a standards body seems like a void that needs to be filled quickly

Reviewer 5:
This reviewer said the project team needs to include someone from the DOT or a consultant familiar with DOT projects to ensure coordination. There are DOT projects involving vehicle mileage tax (to replace gasoline tax), electronic license plates and electronic license plate readers, electronic toll collection (based on vehicle miles traveled from a certain point) that may involve requiring collection of driver or vehicle information at an electric charging station. So, this reviewer asserted that it is imperative that the cybersecurity platform and framework not interfere with the information collection requirements imposed by transportation agencies.

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 project appears to have a clear-cut, rational plan for future research under this project. The level of engagement with industry may well identify additional future research needs along the way.

Reviewer 2:
The reviewer stated that the proposed research is sound. However, there are no go/no-go decision points, which need to be added to the schedule.

Reviewer 3:
The reviewer asked what the scope is for productization.

Reviewer 4:
The reviewer said the Future Research highlighted by the test plan will show initial capabilities to threat, but what about procedural responses to various threat types in the various environments and charging levels. It may be in the test plan, but was not presented.

Reviewer 5:
The reviewer said the list of tasks to be accomplished is a tall order.

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

Reviewer 1:
The reviewer said this project addresses the DOE goal of cybersecurity in EV charging architecture.

Reviewer 2:
The reviewer said this is definite a critical issue that we have faced as an OEM. Resolving the cybersecurity concerns is critical to greater penetration of EVs.

Reviewer 3:
This reviewer said the project is focused on absolutely critical activities for cybersecurity, particularly for moving toward standards and requirements. This is an important area to be addressed if these technologies are going to be safely integrated into transportation in the United States.

Reviewer 4:
The reviewer said this is very relevant work as transportation moves into the grid connected space. This is important work on a required system for the reduction of petroleum in the transportation space.

Reviewer 5:
This reviewer noted that no slide or discussion was provided to justify the relevance of this project to DOE's overall goals and objectives. However, this question is moot because this project is somehow relevant; otherwise, DOE would not have funded it.

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 appear to be sufficient at this time.

Reviewer 2:
This reviewer said the resources appear sufficient at this time. It is possible that additional future research needs may be identified that could be worthy of additional funding, particularly to keep this team and industry working group structure together.

Reviewer 3:
The reviewer said there should be sufficient resources to meet requirements. There also should be many applicable similar industries when some portions of the processes might be leveraged from previous work.

Presentation Number: elt207
Presentation Title: Enabling Secure and Resilient XFC: A Software/Hardware Security Co-Design Approach
Principal Investigator: Ryan Gerdes (Virginia Tech)

Presenter
Ryan Gerdes, Virginia Tech

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 and well-planned.

Reviewer 1:
The reviewer said this project is clearly well-thought out and structured. It was a good idea to include resiliency against a cyberattack (maximizing restoring capability of EVSE to function after an attack) and not just detecting, preventing, and thwarting an attack). The consideration of risk identification, failure states, fail-safes, game-theoretic approaches. vulnerability assessment, reachability analysis, moving target defense, deep Q-learning structures, trusted computing bases, secondary communication channels, and sensor redundancy all make for a thoroughly comprehensive approach.

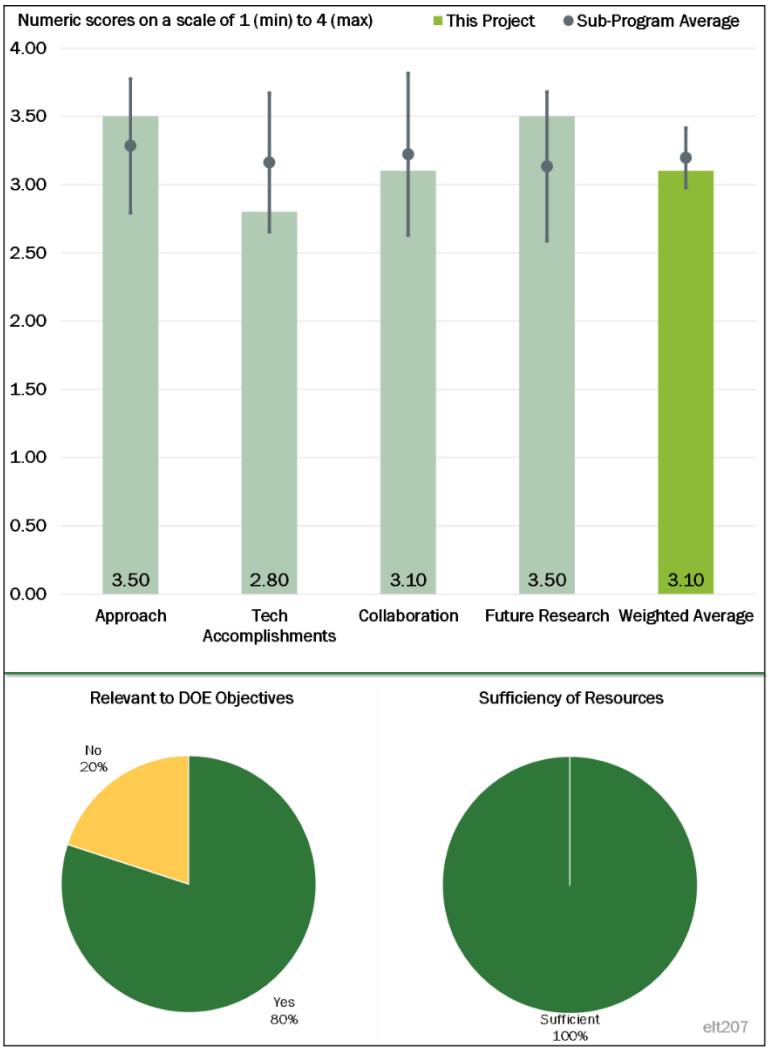

Figure 4-23 – Presentation Number: elt207 Presentation Title: Enabling Secure and Resilient XFC: A Software/Hardware Security Co-Design Approach Principal Investigator: Ryan Gerdes (Virginia Tech)

Reviewer 2:
This reviewer said the approach has a logical plan for addressing both hardware and software in this space, and not just the software standards for cybersecurity. As it is possible to hack into sensors and other hardware leading to compromise of XFC systems, developing hardware defensive strategies is important. The seven-step approach is detailed and appears to be very well planned (although it took a considerable portion of time in the presentation and took away from the accomplishments). The tools and processes being developed to make future assessments easier will be beneficial.

The team is including remote firmware options to make the EVSE software more resilient and avoid the need for an onsite technician to address the inevitable exploited vulnerabilities. The idea of using nearby Bluetooth-connected phones, as a data connection to download firmware if the main communication channel is down, is novel.

Reviewer 3:
The reviewer said the approach is extremely well defined in a series of seven specific feasible tasks that cover the range of critical issues. These tasks use original state-of-the-art approaches to address each element. These include the use of game theoretic risk analysis and automatic attack assessment tools to specify attacker characteristics, attack vectors, and assets; experimentally validated microgrid modeling; the use of deep learning to develop a moving target defense for sensor and actuator attacks; the design of attack resistant battery management systems; device fingerprinting; and trusted firmware updates. There are also seven specific milestones with clear descriptions to show accomplishment of these goals.

Reviewer 4:
The reviewer stated that the approach is sound and well planned

Reviewer 5:
The reviewer said that with respect to the project approach, as this effort only started a few months before having to submit AMR slides, the proposed approach was perhaps the most fully fleshed out portion of the presentation. Approach details were provided on seven different tasks, including the overall plan to use the Bronzeville Community Microgrid as a testbed, and specific efforts to conduct system vulnerability assessments, to validate models to use for scenario analyses, and to evaluate strategies for defending attacks and for maintaining some level of operation capability even after system compromise. The reviewer thought it was good that the project recognizes that maintaining resilience and operational functionality is of paramount importance, as overly conservative approaches of totally disabling the charging system in response to suspected cyber-attacks would lead to a very negative user experience.

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

Reviewer 1:
The reviewer said that this project is in its first year and only 20% complete, but the progress has been substantial, particularly in the areas of the development of the threat assessment methodology, including validation on a BEV testbed; the development of trust models, including successful demonstration of the game theoretic approach; the microgrid modeling; the development of sensor and actuator defense mechanisms; and the design of a battery management system.

Reviewer 2:
The reviewer noted that a delay in contracting is pushing the schedule back about a quarter, but the team has demonstrated good accomplishments nonetheless, given that the project is about halfway done. A possible concern is the use of an older BEV that may not have the most up-to-date software, but this may not be a major concern as the focus here is on EVSE. In general, the team is well underway in gaining the basic understanding of system vulnerabilities across the EV/EVSE system.

Reviewer 3:
The reviewer said the project is only fairly recently started, but progress was nevertheless reported on several of the tasks. Progress seems satisfactory so far, and will hopefully fully realize the first year goals by the end of 2019.

Reviewer 4:
The reviewer stated that it appears this project is somewhat behind schedule. No milestone schedule was provided. The project started in October 2018 and ends December 2020. It is only 20% completed, when it should be closer to being 30% completed.

Reviewer 5:
The reviewer said this is a new project with relatively little accomplished to date.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said this team has built a good academic and industry partnership. There is a good balance of industry and academia participation across the tasks. The team has the right partners onboard: an OEM; an EVSE provider; a utility; and a cybersecurity company.

Reviewer 2:
This reviewer stated that all the collaborators are all leaders in this field. The roles of each collaborator are well defined, and there is a structured plan for regular communication between the partners.

Reviewer 3:
The reviewer said this team is well formed with charging infrastructure and automotive OEMs represented. There has not been significant collaboration to date.

Reviewer 4:
The reviewer said this project includes a large number of partners between several universities and private companies—including a charging system operator, an electric utility, a major automaker, and a security firm. This seems to bring the right mix of partners to the table for pursuing the project goals. There are quite a few different tasks across which contributions from the different partners are spread, so coordination to get valuable and organized output from everyone may be challenging. Hopefully, the team will be successful with this.

Reviewer 5:
The reviewer said the project team needs to have as partners, or somehow collaborate, with DHS and DOT to ensure there is no duplication in protection of critical infrastructure or interference with the collection of information on vehicle location, vehicle miles traveled, electronic license plates, moving violations, and so forth by a transportation or vehicle enforcement agency. DHS has jurisdiction over protection of critical infrastructure, including the electric grid. DOT has jurisdiction over transportation safety and collection of certain taxes and tolls for transportation purposes.

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 proposed future research plan looks logical and capable of achieving the project goals. The team has outlined a very detailed series of tasks to complete the project.

Reviewer 2:
This reviewer said the proposed future research is well-defined, with clear tasks and milestones specifically addressing the remaining challenges and barriers.

Reviewer 3:
The reviewer stated that the future work plan seems to be appropriately executing on the established project approach as the effort ramps up to full capacity.

Reviewer 4:
The reviewer saw no issues.

Reviewer 5:
This reviewer thought that the planned tasks are well documented and very relevant. The reviewer believed that this is an aggressive project with many goals. It may be difficult to accomplish everything that is planned.

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

Reviewer 1:
The reviewer believed that this project is relevant and aligned to DOE objectives to enable XFC and more marketable EVs. In addition to the XFC, the cybersecurity elements of the project are critical to a safe and resilient grid interface.

Reviewer 2:
The reviewer said ensuring that EV charging systems can operate in a secure and efficient manner, particularly as vehicle penetration rates and charging levels increase, is certainly relevant to the mission of DOE and the VTO. The project's focus on ensuring resilient, and not just secure system operation, is also quite relevant.

Reviewer 3:
This reviewer said the project is relevant to VTO objectives because it will facilitate the safe and secure deployment of XFC systems that are resilient against threats or compromise, which will in turn enable more deployment of EVs that meet DOE efficiency goals.

Reviewer 4:
The reviewer stated that cybersecurity is an essential element in building trust in electric and connected vehicles, leading to their widespread adoption, and thus is highly relevant to the DOE goals.

Reviewer 5:
The reviewer said this question is moot. Even though there was no slide showing the DOE overall goals and objectives to which this project is relevant, DOE has funded this project; it would not have funded this project otherwise unless it was somehow 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 this project is well funded and there is no indication that the resources are inadequate.

Reviewer 2:
As far as this reviewer can tell, the resources seem sufficient for completing the project.

Reviewer 3:
This reviewer said the resources (funding and partner expertise) are sufficient for this project to achieve its goals successfully.

Reviewer 4:
The reviewer stated that the resources for this project are extremely high at over $3 million for only 2 years of work. However, the scope is extremely large and ambitious, so the funding is in line with the anticipated contributions.

Presentation Number: elt208
Presentation Title: Highly Integrated Power Module
Principal Investigator: Emre Gurpinar (Oak Ridge National Laboratory)

Presenter
Emre Gurpinar, 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 and well-planned.

Reviewer 1:
The reviewer said this project is well defined and planned out. The challenges have been properly defined, and the plan is adequate to evaluate the technologies.

Reviewer 2:
This reviewer said that finding a replacement, low cost, for direct bonded aluminum (DBA)/direct bonded copper (DBC) using insulated metal substrate (IMS) with thermal pyrolytic graphite (TPG) looks interesting. Evaluating quilted gate drivers and their associated auxiliary circuit, if proven successful could enable smaller, electrically quieter inverters.

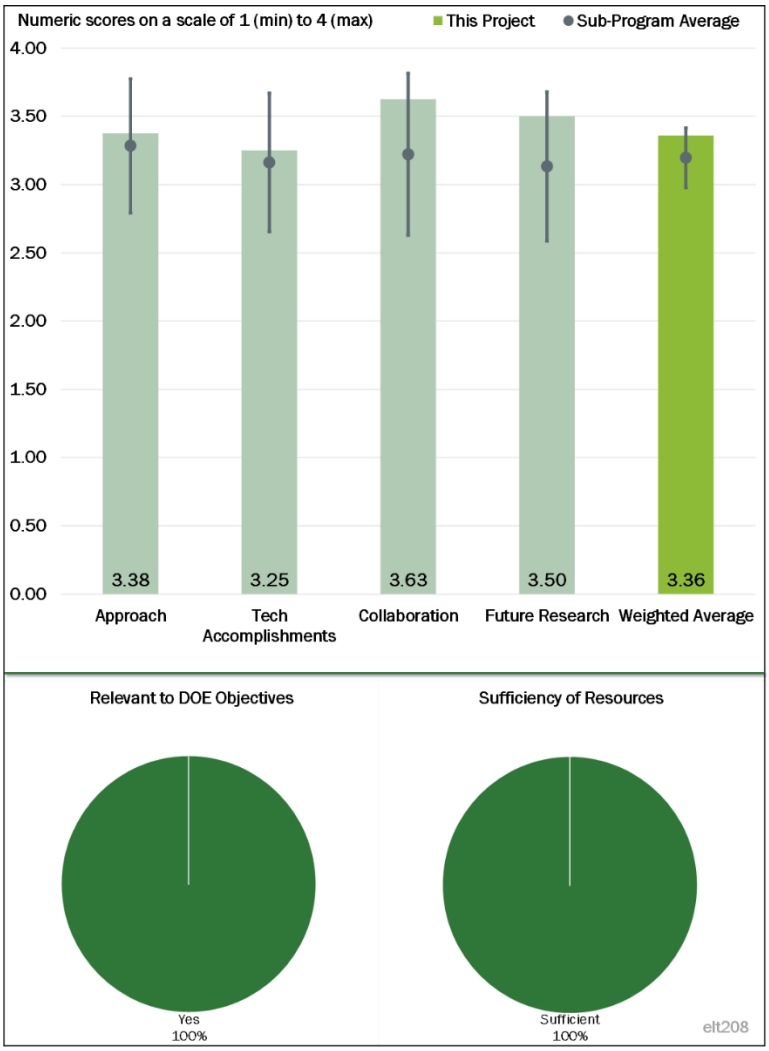

Figure 4-24 – Presentation Number: elt208 Presentation Title: Highly Integrated Power Module Principal Investigator: Emre Gurpinar (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer said the approaches address the need for low-cost substrate, miniaturization, and integration of gate-drive circuit, and interconnect for low-inductance module packaging. However, this reviewer is not sure about the benefit of the Quilt interconnect technique for power module packaging. It is a novel technique for making a large "chip" out of small individual chips with a minimum spacing between the chips and for joining functional chips together with low interconnect inductance. It may be used for a cascode-configured gallium nitride (GaN) device where a silicon (Si) metal–oxide–semiconductor field-effect transistor (MOSFET) is co-packaged with a depletion-mode GaN chip to make a normally-off switch. The reviewer remarked the Quilt interconnect would eliminate the inductance between the MOSFET and GaN chip. But for this to happen, one has to work hard to convince the device manufacturers to make the device metallization and thicknesses of their chips compatible for "Quilting". If the Quilt technique is used to join multiple insulated-gate bipolar transistor (IGBT) or MOSFET chips together in a half-bridge configuration, the benefit realized in the chip-to-chip inductance reduction may well be offset by the added challenges for cooling, thermo-mechanical stresses at the Quilt joints, and die-attach on a rough/distorted substrate. If the technique is used to join IGBT chips

with free-wheeling diode chips, then one has to deal with the fact that the two types of devices normally do not have the same thickness. Overall, this reviewer felt that to implement the interconnect technique, power module packaging people would have to climb a steep uphill to convince the device manufacturers to substantially change their device metallization schemes, and, this will be problematic when the benefit does not seem to be substantial.

Reviewer 4:
This reviewer said the metrics to address total cost were not addressed in this work. Even if specific cost targets cannot be developed or disclosed, the team should clearly identify total system costs and identify pathways to address them.

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

Reviewer 1:
This reviewer said the early objectives have been adequately met. 2019 will be a critical year to determine the progress toward the primary object of the project.

Reviewer 2:
The reviewer stated that excellent progress has been made on substrate evaluations and gate-drive development.

Reviewer 3:
The reviewer said the initial thermal tests of IMS with TPG look encouraging, as well as the quilted package approach for the gate drivers and their auxiliary components.

Reviewer 4:
The reviewer said there was no justification presented that indicated that mean junction temperature is a good predictor of mean time between failures (MTBF), other than a hypothesis that quilting would inherently address this issue. More effort should be considered to understand key mechanical failure modes.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer stated that the coordination with Indiana IC is well coordinated, and the quilting technique is quite novel.

Reviewer 2:
The reviewer observed a highly qualified team of researchers for collaboration.

Reviewer 3:
This reviewer noted the team seems to have kicked off the project with a good project management plan. No major issues with this approach were noted.

Reviewer 4:
It appeared to this reviewer that the labs and suppliers are working well together to develop the technology.

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 proposed future work is aligned with the objectives of the project. The PI understands the risks and challenges and has developed a plan to evaluate the technologies and arrive at the best solution.

Reviewer 2:
The reviewer said the future efforts planned are good. The team may need to pivot based on emerging learnings cascaded from the consortia.

Reviewer 3:
The reviewer noted that the goal for 2019 is completing the analysis of what the project team started. Building and testing a new power module using the new technologies is a logical next step for 2020.

Reviewer 4:
This reviewer suggested that future work on the Quilt interconnect may involve reaching out to a power device manufacturer to get their interest in making the chips compatible with the Quilting technique.

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

Reviewer 1:
The reviewer said this project is relevant and addresses the need for high power-density, low-cost, and high-reliability power electronics in direct alignment with the DOE VTO ELT objectives.

Reviewer 2:
The reviewer stated that this project is aligned to DOE objectives for energy efficiency.

Reviewer 3:
This reviewer said that working to meet the DOE ELT 2025 targets using this new technology supports the DOE objectives.

Reviewer 4:
This reviewer believed that miniaturization of the inverter is critical to meeting the 2025 targets, but cost is also critical. The project seems to be lacking as it relates to understanding the cost of the proposed technologies.

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 it seems that the funding and resources are adequate for the objectives of the project.

Reviewer 2:
The reviewer said the resources seem sufficient to meet objectives of the research.

Reviewer 3:
The reviewer said it appears the labs and their suppliers are working well together.

Presentation Number: elt209
Presentation Title: High-Voltage, High-Power Density Traction Drive Inverter
Principal Investigator: Gui-Jia Su (Oak Ridge National Laboratory)

Presenter
Gui-Jia Su, 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 and well-planned.

Reviewer 1:
The reviewer said that an excellent approach has been proposed by the PI to increase the inverter power density by segmenting the conventional inverter topology into two interleaving inverters, which leads to reduction or elimination of a bulky bus capacitor. Removal of the capacitor also improves the reliability of the inverter.

Reviewer 2:
This reviewer said that changing the switching approach to cancel/lower the capacitor ripple currents is a good idea. Optimizing the bus bar design for better cooling and lower inductance, as well as increasing the DC bus voltage should help reduce the size of the inverter. A good possible approach.

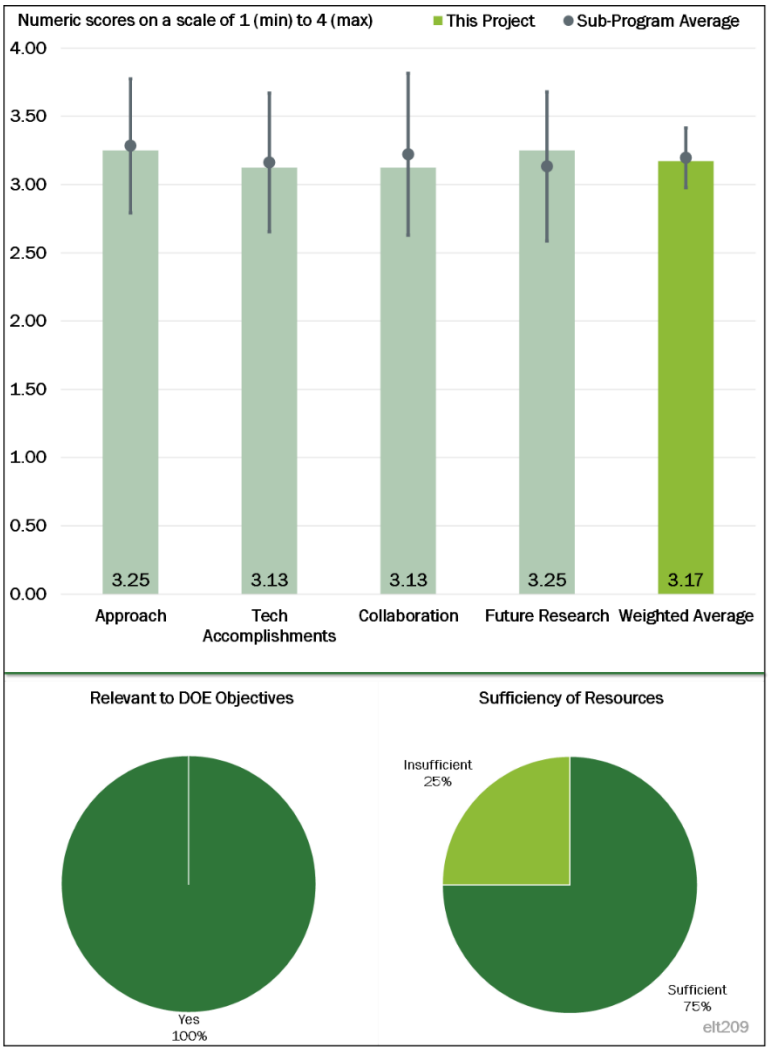

Figure 4-25 – Presentation Number: elt209 Presentation Title: High-Voltage, High-Power Density Traction Drive Inverter Principal Investigator: Gui-Jia Su (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer said the plan seems adequate, but the presentation is very early in the project. The project does not discuss the potential to the electric machine and machine control with multiphase and segmented inverter topologies.

Reviewer 4:
The reviewer stated that investigating 6-phase motor and effects on current ripple is a good practice, however, this design is more suitable for higher power motors where required current is above 450 to 500 Arms, and this design splits the current to half. For a 100 kW motor this design will increase the hardware and cost, power module requires 6 output, and gate drive will be doubled.

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

Reviewer 1:
The reviewer noted that the PI has done a lot of simulations to prove the feasibility of the proposed approach. Excellent progress so far. Keep up the good work.

Reviewer 2:
The reviewer noted the good results on current reduction calculations, of course 70% reduction seems too high, but the reviewer gives the project team the benefit of the doubt. If the voltage is increased to 800 the current is reduced to half. Therefore, the reviewer asked why the project team needs to use a 6-phase system to cut the current phase more.

Reviewer 3:
The reviewer said the project is showing the possibilities of lower ripple currents with new switching topologies. The reviewer asked if the team can quantify the possible change in capacitance as well as the potential size reduction of the capacitor. The reviewer also asked how system cost is affected by adding more power switches to the inverter and more windings to the motor to help cancel cap ripple voltages.

Reviewer 4:
The reviewer noted that this is very early in the project. No significant progress made to date.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that this is a very strong team to support the work.

Reviewer 2:
The reviewer noted that ORNL is doing the design of a new inverter, and it does not appear that NREL, their partner, has started yet.

Reviewer 3:
It seems to this reviewer like no industry partner is selected for this project. It would be a good practice to involve an inverter supplier who is participant in the activity and would benefit from the outcome of the study.

Reviewer 4:
The reviewer noted that the entire project is National Laboratory-based. ORNL and NREL are the only participants. The project would benefit from adding OEMs for advisory recommendations and some oversight.

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 project is adequately planned to achieve proposed objectives.

Reviewer 2:
The reviewer stated that it is well-planned future work.

Reviewer 3:
The reviewer said that fixing gaps in previous designs, investigating embedding and distributed capacitors is a good approach for possible inverter size/cost reductions.

Reviewer 4:
For a 100 kW inverter, this reviewer does not see why it is necessary to go to an 800V battery. There may not be enough cells to put in series to get 800V depending on the kWh needed. The reviewer asked when the gate drive design will be started and what is specific about that.

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

Reviewer 1:
The reviewer said this project clearly supports the DOE VTO ELT objectives for making power electronics of electric drives to have higher power density, lower cost, and higher reliability.

Reviewer 2:
The reviewer stated that the project team is working towards the ELT 2025 targets, which meets the DOE objectives

Reviewer 3:
The reviewer stated that the project is aligned with the objectives for inverter power density. However, the reviewer sees no attempt being made to properly understand the potential cost or alignment to DOE cost targets.

Reviewer 4:
The reviewer noted that the selected topology may help reduce the capacitor, but it adds gate driver, more phases on power module and motor, which requires more space for interface. So the project would not reduce the space or 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 with NREL assisting with the thermal issues, and ORNL working with new design concepts, the resources look sufficient.

Reviewer 2:
The reviewer said the resources may be sufficient, but the selected topology is not suitable for a 100kW system. 6-phase is a solution if current is too high in a high-power system.

Reviewer 3:
The reviewer suggested that some resources could be diverted to track alignment to cost objectives. Also, the project needs to comprehend the impact to the electric machine, machine controls, and impact to vehicle relative to AC current ripple.

Reviewer 4:
The reviewer said the budget seems too tight for building the hardware to validate the proposed approach.

Presentation Number: elt210
Presentation Title: Development of Next-Generation Vertical Gallium-Nitride Devices for High-Power Density Electric Drivetrain
Principal Investigator: Greg Pickrell (Sandia National Laboratories)

Presenter
Greg Pickrell, Sandia National Laboratories

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 and well-planned.

Reviewer 1:
The reviewer said the plan seems adequate and aligned. The plan will address challenges and problems.

Reviewer 2:
The reviewer noted that the key technical barriers for incorporating very advanced wide bandgap semiconductors into automotive design seem to be addressed in this effort.

Reviewer 3:
The reviewer said the project team's approach to looking at the system, evaluating commercial off-the-shelf technology, investigating new materials for both power devices and passives should establish a baseline for them to improve upon. The reviewer asked how higher switching speeds affect the motor from a systems approach.

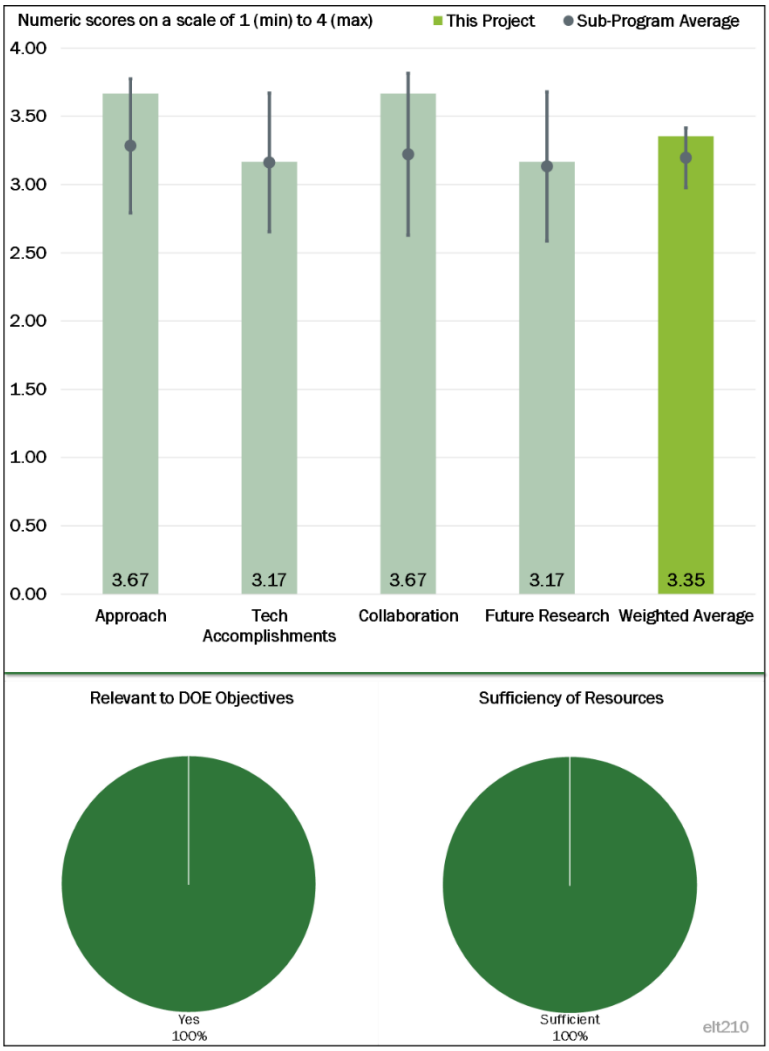

Figure 4-26 – Presentation Number: elt210 Presentation Title: Development of Next-Generation Vertical Gallium-Nitride Devices for High-Power Density Electric Drivetrain Principal Investigator: Greg Pickrell (Sandia National Laboratories)

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

Reviewer 1:
The reviewer said the project appears to be on track to meeting the technical goals of the overall described objectives. However, it is somewhat unclear what the plan is to address translation of GaN into an automotive cost/performance hardware component. It may be too early to focus on this yet, but still should be addressed at some point in the project.

Reviewer 2:
The reviewer noted that this is a new project, and little progress has been made to date.

Reviewer 3:
The reviewer noted that the project team appears to be focused on vertical GaN devices in the long term. The reviewer asked whether there are some improvements that could be made to make silicon carbide (SiC) more competitive. It would be useful to know what target specifications, as opposed to today's specifications, the team is working toward. Spec sheets would be beneficial for the passives and the power devices. If possible, quantify your version of improvement.

In automotive, if you cannot meet the reliability target, cost does not matter—it will not be used. Perhaps it should be the lowest cost that meets all requirements. State your target requirements.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said the project has a diverse team and has all bases covered with the team.

Reviewer 2:
The reviewer stated that the team seems to be well aligned internally and coordination between the parties is very good.

Reviewer 3:
The reviewer said the PI should consider having someone from the automotive industry as part of your team. The team appears to be capable of addressing the tasks defined.

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 thought the project is well planned and staffed. The project has a realistic plan to evaluate the technologies. The project team has addressed issues and challenges and their proposed plan is more than adequate.

Reviewer 2:
The reviewer said the future work plan to study SiC and GaN to address technical barriers are clear, but manufacturability and system design costs are not clearly articulated in the future work plan that was shown. These are key to adoption by the transportation industry.

Reviewer 3:
The reviewer suggested trying to quantify what you are striving for. Evaluate performance against Consortium targets—these should be your starting points, let us see them.

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

Reviewer 1:
This reviewer said the project is aligned to addressing the technical barriers, which are needed to meet the DOE objectives of improved energy utilization.

Reviewer 2:
The reviewers said this project is aligned with meeting power density targets, but may be a bit aggressive as it relates to cost. GaN devices have not been evaluated for potential cost and supply base.

Reviewer 3:
The reviewer noted that the following is stated on the project's Objectives slide (Slide 3): "Power electronics performance targets enable overall system performance targets for the Electric Traction Drive system of 33 kW/L, $6/kW, and > 300k mile operation lifetimes".

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 seem sufficient for this project to meet the stated objectives.

Reviewer 2:
The reviewer stated that the resources seem sufficient to cover the tasks proposed.

Reviewer 3:
The reviewer said there was no discussion of resource shortages. However, the project is quite extensive and aggressive. It will require excellent project management and oversight to achieve the aggressive objectives.

Presentation Number: elt211
Presentation Title: Power Electronics Thermal Management
Principal Investigator: Gilbert Moreno (National Renewable Energy Laboratory)

Presenter
Gilbert Moreno, National Renewable Energy 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 and well-planned.

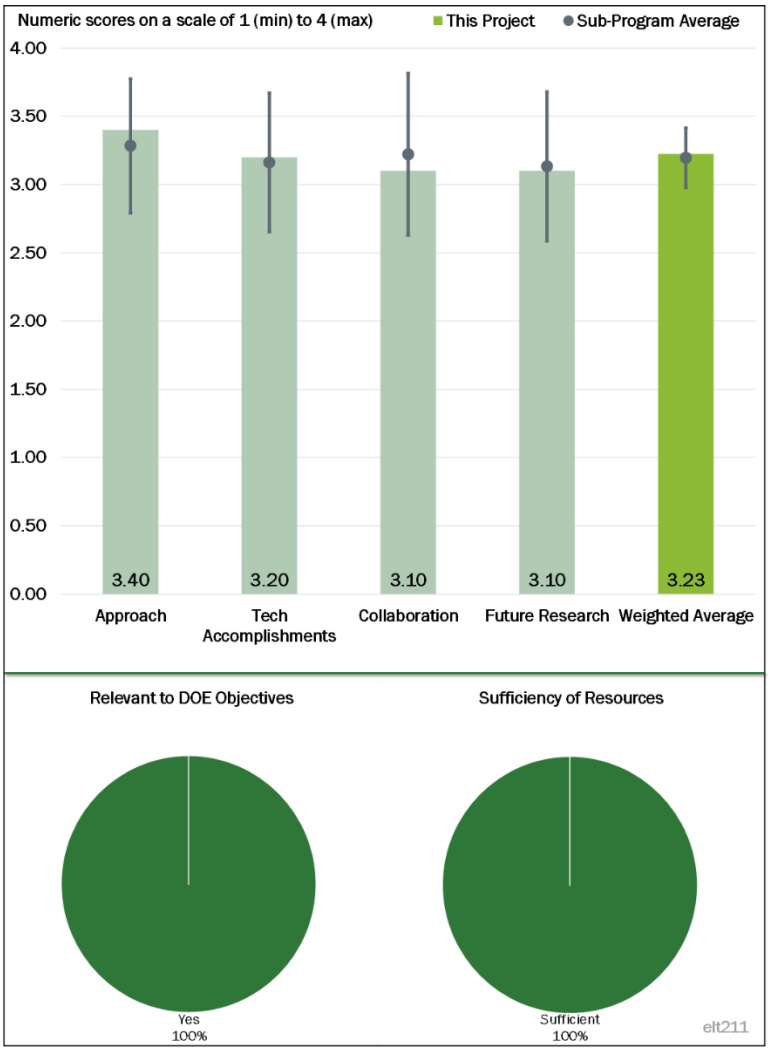

Figure 4-27 – Presentation Number: elt211 Presentation Title: Power Electronics Thermal Management Principal Investigator: Gilbert Moreno (National Renewable Energy Laboratory)

Reviewer 1:
This reviewer thought the plan and approach is sound.

Reviewer 2:
The reviewer noted that combination of simulation and experiment are being used to develop thermal management design concepts to meet DOE goals of 100 kW/L power density. The focus is on two-phase cooling techniques, which are, most likely, the only techniques with sufficient cooling power to achieve these levels of power density. The approach has a nice balance of initial finite element analysis (FEA) and computational fluid dynamics (CFD) simulation to downselect potential cooling technologies; characterization of the thermal performance of a two-phase system for an existing Deere inverter; and experiments to validate the cooling performance of the best candidates to ensure they meet the desired goals.

Reviewer 3:
The reviewer said the technical approach is well conceived, balancing significant concept development via simulation and experimental characterization of the prototype. The technical approach relies heavily on modeling/simulation to evaluate cooling concepts. The reviewer asked if the models have been previously validated. The project tasks focused on prototyping and experimental testing appear slightly less structured and rigorous than the simulation work. Perhaps an explanation of the long-term objective and process/methods for the experimental work would help in clarifying the path.

Reviewer 4:
The reviewer said that the approach is fine, but the assumptions are not. 250 degrees Celsius (°C) for the die temperature is not feasible. The die may be able to handle this temp, but the bonding or other design

parameters limit the temperature to only a few degrees above IGBT. This comment is based on Infineon, application engineer.

Reviewer 5:
The reviewer said the approach to managing the thermal system design seems to be heavily weighted to meeting the technical objectives, without focusing on the industry barriers to incorporation that include total system cost/weight/package, using carry-over fluids and combined fluid loops.

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

Reviewer 1:
The reviewer stated that although the project has only recently started, a novel cooling concept has already been designed combining jet impingement with finned surfaces that eliminates expensive ceramic materials, provides improved performance over standard direct-bond-copper (DBC) designs, and cools the lower capacitor and gate driver parasitically through the bus bar. Furthermore, the study has examined and ranked potential dielectric fluids. Initial modeling results show a 50% improvement in thermal resistance over the 2014 Accord Hybrid. In addition, a manifold was designed that reduces pumping power, provides even distribution of the coolant to multiple devices, and achieves excellent device temperature uniformity at a lower thermal resistance than the targeted value. Finally, work has already begun on designing the test equipment for the experimental validation including the heaters, the cold plate, and the flow loop.

Reviewer 2:
The reviewer said the technical accomplishment to date are satisfactory. In the evaluation of the cooling concepts, considerations on the weight should be included. Also, comparison with state-of-the art solutions should be updated to more recent results.

Reviewer 3:
The reviewer said testing should be conducted with a feasible die temp of less than 200°C. The temperature data seem a bit questionable, because one of the devices at the inlet has higher temperature than the device by the outlet.

Reviewer 4:
The reviewer stated that this is a relatively new project, and limited work was completed to date.

Reviewer 5:
This reviewer noted the technical accomplishments are good for this project, but fail to address cost and industry adoption barriers.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said this project makes good use of the strengths of its collaborations, including the use of a high-density planar inverter from John Deere, use of three-dimensional (3D) printed metal heat exchanger parts from Elementum3D, expertise in inverter design and power loss from ORNL, and information and samples from various dielectric fluid manufacturers.

Reviewer 2:
The reviewer stated that the level of collaboration across partners is adequate. The leading organization is conducting the large majority of the work, with collaborators providing support and materials.

Reviewer 3:
The reviewer noted the project—working with John Deere, Elementum, and ORNL—brings together a good team of qualified resources.

Reviewer 4:
The reviewer said a power module manufacturer had to be a partner to provide more technical expertise to the project. A heavy equipment manufacturer may not have the necessary know-how to develop a power module.

Reviewer 5:
The reviewer stated the collaboration seems to be good, but there may be a little lack of coordination at the integration level. That is unclear from the work as it was presented.

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

Reviewer 1:
This reviewer thought that the work to date confirms that double-sided cooling with direct cooling of electrical connections has excellent benefits. The key to success of this project will be the ability to package this solution for eventual use in a vehicle. The final selection of the dielectric fluid will also be critical to the adoption of this technology.

Reviewer 2:
The reviewer said the proposed future tasks for the rest of this project are well defined and address the remaining challenges and barriers. It would also be nice to have some information on what additional packaging/cooling concepts could be developed in a follow-on program.

Reviewer 3:
The reviewer stated that the future research challenges outlined in the presentation are adequate. The study focuses more on demonstrating the fundamentals of cooling with dielectric fluids—there will be many more challenges to address to get from this point towards a solution that can be production-ready (reduction of weight/volume/cost, selection of fluid, solutions for heat rejection from coolant). It would be worth creating a thorough list of such challenges and specify which of these challenges could realistically be accomplished as part of the future work and an estimated time required.

Reviewer 4:
The reviewer said the thermal testing of the power module is very critical and should be done correctly. Boiling under the devices should be checked. No information was provided about the John Deere two-phase design. The reviewer asked what the selected design is, whether it is double side direct cooling, and how the pin fin is connected to the DBC.

Reviewer 5:
The reviewer said the future work is good, but does not address some of the more complex issues involved in a real power electronic design. The model system only provides an approximation of real systems, as they will be manufactured. At least some of the future modeling work could be more strongly focused on these aspects.

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

Reviewer 1:
The reviewer noted that this project focuses on developing thermal management solutions capable of dissipating high heating loads generated over very small surface areas of power electronics. In this sense, the

project directly supports the DOE objective of increasing power density in electric machines and energy converters.

Reviewer 2:
The reviewer stated that development of state-of-the-art power module cooling to improve efficiency and space is very critical to the DOE goal of 100 kW/L.

Reviewer 3:
The reviewer said this project addresses the DOE objective of providing enabling technology to address key barriers to adoption of improved energy utilization vehicles.

Reviewer 4:
This reviewer stated that thermal considerations are very often the limitation in achieving power density goals, such as DOE's ambitious 100 kW/L volume goal. While improved device efficiency can reduce power loss percentage, it is almost ensured that such large increases in overall power density will result in higher heat fluxes, which must be removed for optimal device functioning. Thus, addressing the thermal issues upfront in the design phase through incorporating new cooling technologies is critical for meeting the goals in a timely manner.

Reviewer 5:
The reviewer said this project is aligned with reduced cost and power density targets. The complex heatsink could be a problem for eventual adoption—the thermal advantages are somewhat clear, but the implementation issues are many and need to be resolved.

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 appear adequate to support the research project

Reviewer 2:
The reviewer stated that the resources seem adequate, and the team is well composed.

Reviewer 3:
This reviewer said the resources seem to be adequate to meet the objectives of this project.

Reviewer 4:
This reviewer said that while the limited resources are sufficient to achieve the goals of this project, the effort to identify and develop new thermal management technologies is crucial to meeting the DOE's stated goal of 100 kW/L power density by 2025. Additional funding would allow an even more thorough investigation of more potential technologies, potentially leading to improved designs that could meet or exceed DOE targets.

Reviewer 5:
The funding is sufficient, but this reviewer thought the right resources are not assigned to the project. Infineon or Cree or another major power module supplier should have been selected to participate in this project.

Presentation Number: elt212
Presentation Title: Non-Heavy Rare-Earth High-Speed Motors
Principal Investigator: Tsarafidy Raminosoa (Oak Ridge National Laboratory)

Presenter
Tsarafidy Raminosoa, Oak Ridge National Laboratory

Reviewer Sample Size
A total of one reviewer evaluated this project.

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

Reviewer 1:
The reviewer said the machine topologies investigated are not novel and it is hard to see how any of them will lead to the significant required increase in power density.

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

Reviewer 1:
The reviewer stated that the results presented so far focused on electromagnetic performance. There are still significant mechanical and thermal challenges to be addressed and a detailed mechanical and thermal analysis is needed. Also, alternating current (AC) effects and losses are not accounted for, and hence the presented efficiency values are too high.

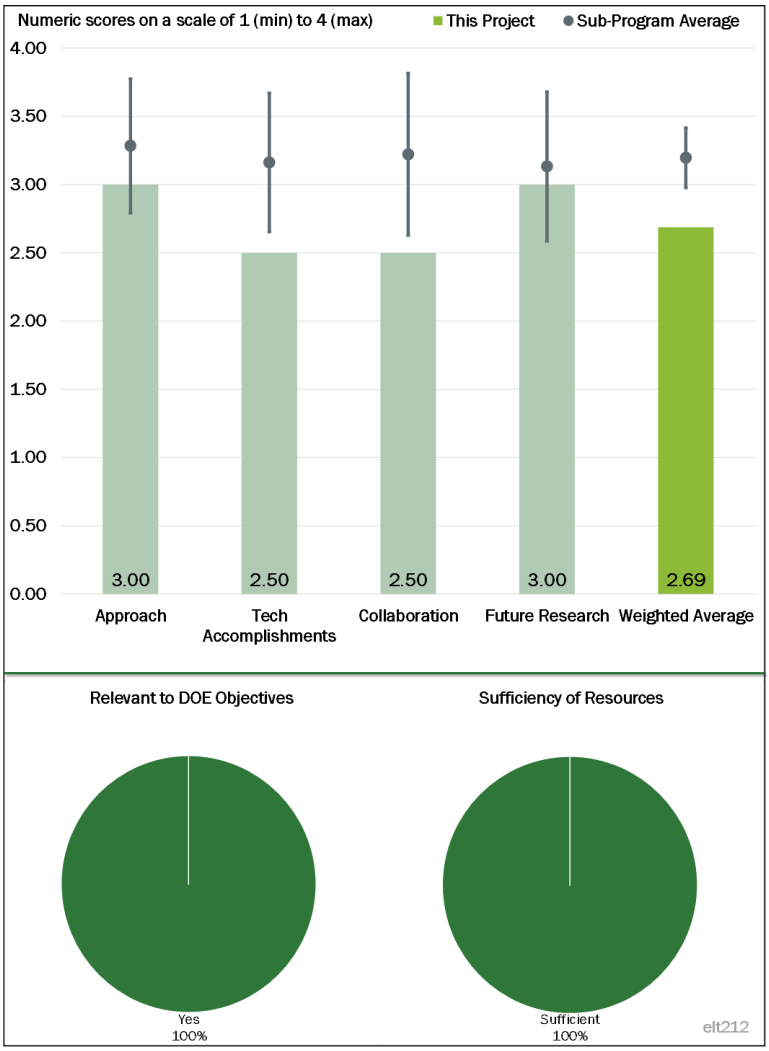

Figure 4-28 – Presentation Number: elt212 Presentation Title: Non-Heavy Rare-Earth High-Speed Motors Principal Investigator: Tsarafidy Raminosoa (Oak Ridge National Laboratory)

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted that even though NREL and Ames are listed as collaborators, their role so far is not very 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 said there is good recognition that mechanical and thermal analysis are needed for such high-speed high-frequency designs.

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

Reviewer 1:
The reviewer said the pursued designs have some merits, but there are also significant challenges involved, and more work and results are needed to show that there is a realistic path to meet the DOE objectives

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

Reviewer 1:
The reviewer said that based on the level of proposed effort, the resources seem to be sufficient

Presentation Number: elt213
Presentation Title: High-Fidelity Multiphysics Material Models for Electric Motors
Principal Investigator: Jason Pries (Oak Ridge National Laboratory)

Presenter
Jason Pries, Oak Ridge National Laboratory

Reviewer Sample Size
A total of one reviewer evaluated this project.

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

Reviewer 1:
It is not clear to this reviewer what the impact of the proposed approach will be on meeting the DOE objectives. A comparison of the improved demagnetization modeling/analysis to demagnetization analysis in commercially available packages should be included. Also, it is not clear that demagnetization analysis is the one that presents a high level of inaccuracy.

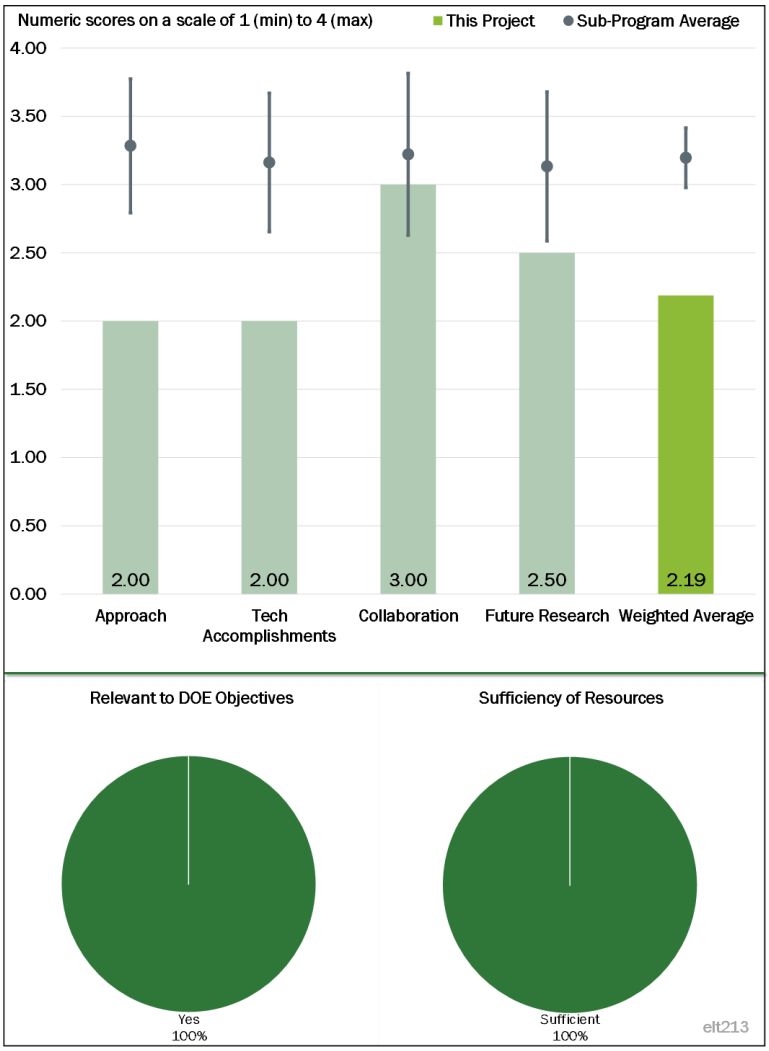

Figure 4-29 – Presentation Number: elt213 Presentation Title: High-Fidelity Multiphysics Material Models for Electric Motors Principal Investigator: Jason Pries (Oak Ridge National Laboratory)

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

Reviewer 1:
It is unclear to this reviewer what the impact of the proposed approach will be on meeting the DOE objectives. A comparison of the improved demagnetization modeling/analysis to demagnetization analysis in commercially available packages should be included. Pulse-width modulation (PWM) losses and in general high frequency losses in the magnets should be evaluated. Also, the highest level of inaccuracy is usually in the evaluation of core losses. This reviewer thought that this should be a significant part of future work

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that there seems to be good collaboration with other National Laboratories and industrial partners.

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

Reviewer 1:
The reviewer stated that a comparison of the improved modeling to commercially available software should be performed. PWM losses should be evaluated. The impact of the improved modeling on the motor performance should be quantified.

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

Reviewer 1:
The reviewer said that a more accurate modeling/analysis is relevant, but more evidence of the impact and the chosen direction is needed.

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

Reviewer 1:
The reviewer said that based on the proposed scope, the resources seem to be sufficient.

Presentation Number: elt214
Presentation Title: Electric Motor Thermal Management
Principal Investigator: Kevin Bennion (National Renewable Energy Laboratory)

Presenter
Kevin Bennion, 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 and well-planned.

Reviewer 1:
The reviewer said it looks like a good fundamental approach to achieve accurate measurements by ensuring that that measurement technique has as little inherent variability as possible. The approach for future thermal interface work was not defined. The reviewer would like to see that.

Reviewer 2:
This reviewer said that even though material and thermal interface characterization can lead to more accurate performance predictions, it is not clear that the proposed approach will lead to a significant improvement in thermal management or meeting the 10X required improvement in motor density

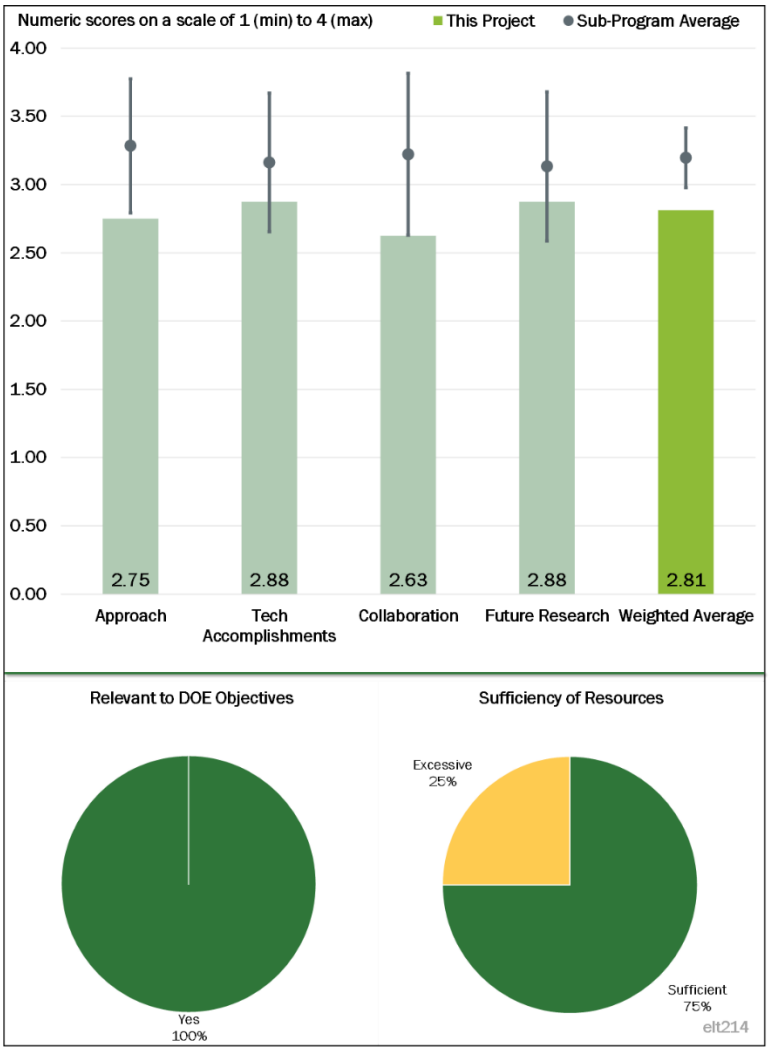

Figure 4-30 – Presentation Number: elt214 Presentation Title: Electric Motor Thermal Management Principal Investigator: Kevin Bennion (National Renewable Energy Laboratory)

Reviewer 3:
The reviewer said the approach is not innovative.

Reviewer 4:
The reviewer stated that this is very generic research, and speculated that this work was done in 2012.

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

Reviewer 1:
This reviewer observed good results showing a significant reduction in error.

Reviewer 2:
The reviewer said that a reasonable project has been made, but the impact on the motor performance needs to be quantified.

Reviewer 3:
This reviewer stated that so far, the work is very general. Studying the heat transfer measurement between different materials is explored. While some of these findings can help motor designers to model their motor more accurately, there is much more involved in motor thermal management.

Reviewer 4:
The reviewer said that this project's approach is not new.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer asked who the industry partners are—the motor suppliers and end users.

Reviewer 2:
The reviewer said that it sounds like the collaboration is happening, but it would be nice to see more evidence in the material. The reviewer asked if the PI can show a work output from the collaborators.

Reviewer 3:
This reviewer stated that even though several other National Laboratories are listed as collaborators, the level of collaboration does not seem to be significant at this point in time.

Reviewer 4:
The reviewer said the collaboration plan is not that needed for 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 these are good topics for future work, like the thermal interface investigation and the impact of thermal cycles on material properties.

Reviewer 2:
The reviewer said the proposed future work is useful, but more emphasis on novel thermal management schemes should be considered.

Reviewer 3:
This reviewer stated that the work completed so far is needed for future studies, but the progress is not sufficient. We need innovative motor cooling to increase the power density by tenfold.

Reviewer 4:
This reviewer said there is no significance in the future research.

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

Reviewer 1:
This reviewer stated that optimized motor design will require knowing the correct thermal properties of design materials. This work looks to be very well aligned with that need, and will provide methods and maybe eventually data on material properties to help designers.

Reviewer 2:
The reviewer explained that developing better cooling topologies and times are needed to increase power density. Hopefully, the project helps with this challenge.

Reviewer 3:
This reviewer said material and thermal interface characterization will help improve the motor thermal performance, but development of novel thermal management schemes is needed.

Reviewer 4:
The reviewer said this project might be relevant to the efficiency requirement.

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

Reviewer 1:
This reviewer said that based on the proposed scope of work, the resources seem sufficient

Reviewer 2:
The reviewer said the resources seem fine.

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

Reviewer 4:
This reviewer said the project team needs to run actual motor thermal testing to correlate the findings. The reviewer asked why a stranded stator is used—most motors are bar wire for automotive applications.

Presentation Number: elt215
Presentation Title: Permanent Magnets without Critical Rare Earths to Enable Electric Drive Motors with Exceptional Power Density
Principal Investigator: Iver Anderson (Ames Laboratory)

Presenter
Iver Anderson, Ames 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 and well-planned.

Reviewer 1:
The reviewer remarked that using fine grain powder is an excellent method to reduce the heavy rare-earth (HRE) material, if a good process is developed.

Reviewer 2:
The reviewer stated that the development of sustainable high-performance magnetic materials is critical.

Reviewer 3:
The reviewer noted that while there are some challenges, the approach looks good and the data support that the approach is working. The team seems to understand the challenges with the approach and has a path of investigation to mitigate issues.

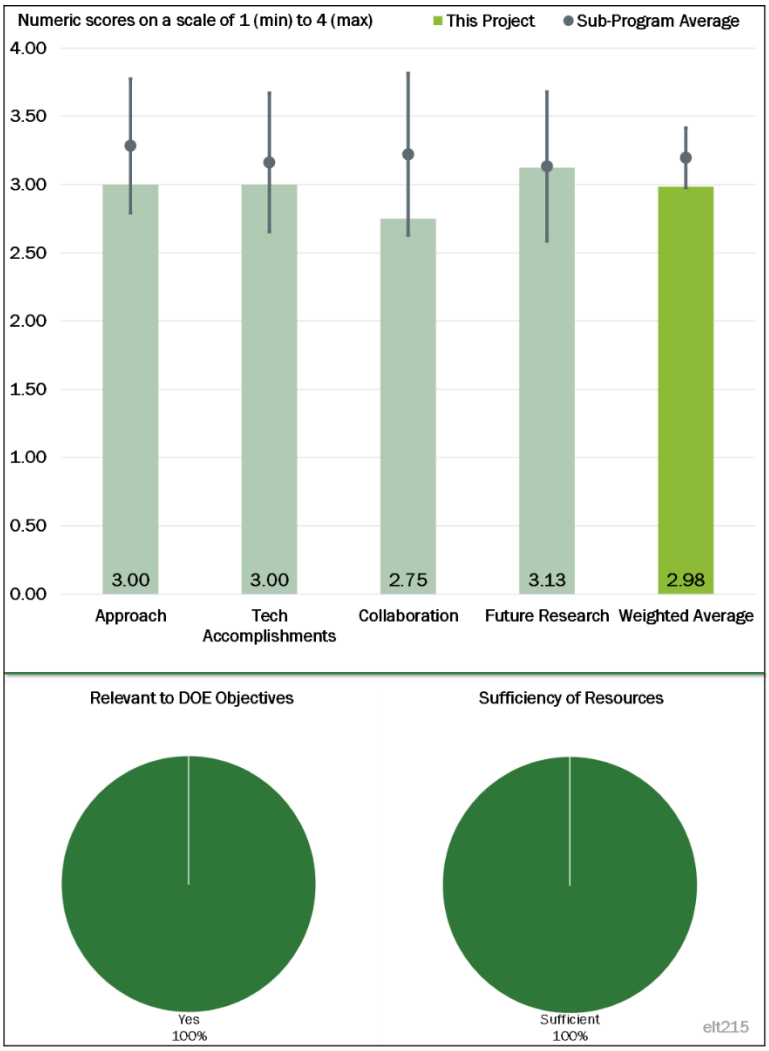

Figure 4-31 – Presentation Number: elt215 Presentation Title: Permanent Magnets without Critical Rare Earths to Enable Electric Drive Motors with Exceptional Power Density Principal Investigator: Iver Anderson (Ames Laboratory)

Reviewer 4:
This reviewer said it is not clear that what the impact of the HRE permanent magnet (PM) will have on the motor performance. The reviewer also asked how it compares to commercially available dysprosium (Dy)-free magnets. The graded magnet approach seems very difficult, and physically using blocks of different magnets might be an easier path.

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

Reviewer 1:
The reviewer said the project showed good results from grain size reduction to help coercivity. That is a good first step.

Reviewer 2:
The reviewer stated that the project is progressing smoothly.

Reviewer 3:
This reviewer pointed out that many questions still need to be answered regarding flammability control and molding process, and inquired about the target coercivity or maximum temperature under 80%.

Reviewer 4:
The reviewer said it is not clear that what the impact of the HRE PM will have on the motor performance, and asked how it compares to commercially available Dy-free magnets. The graded magnet approach seems very difficult, and physically using blocks of different magnets might be an easier path.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said the team seems to have the right collaboration, and it would be good to show more evidence of work output from the collaborators.

Reviewer 2:
The reviewer said the collaboration plan is feasible.

Reviewer 3:
The reviewer noted that there are several other National Laboratories listed as collaborators, but the level of collaboration is not clear yet. One critical area of collaboration is to work with ORNL on evaluating the impact of the expected properties of the developed magnets on the motor performance.

Reviewer 4:
The reviewer said that a magnet supplier should have been involved in the project to provide industry feedback to the team.

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

Reviewer 1:
The reviewer said it is not clear that what the impact of the HRE PM will have on the motor performance, and asked how it compares to commercially available Dy-free magnets. The graded magnet approach seems very difficult, and physically using blocks of different magnets might be an easier path.

Reviewer 2:
The reviewer stated that working on better grain size control looks good. Working on graded magnet to place the right properties where needed looks good.

Reviewer 3:
The reviewer said the future plan is feasible.

Reviewer 4:
This reviewer asked how the unanswered process question is going to be investigated. Need a little more detail on the next steps.

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

Reviewer 1:
The reviewer said that removing HRE elements, while keeping high power density, is in line with the DOE objectives to reduce cost of motors and improve the performance.

Reviewer 2:
The reviewer stated that this project is relevant to DOE's goal to reduce the need for rare-earth materials.

Reviewer 3:
This reviewer said the project helps with the reduction of the motor price if performance is kept the same as magnets with rare-earth or grain boundary diffusion process (GBDP) type magnets.

Reviewer 4:
The reviewer said this project is potentially relevant, but more quantitative data of the expected impact on motor performance is needed

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

Reviewer 1:
The reviewer remarked resources are sufficient.

Reviewer 2:
The reviewer stated resources seem sufficient.

Reviewer 3:
This reviewer said that based on the proposed scope, the resources seem sufficient.

Reviewer 4:
The reviewer stated that the funding seems to be adequate for this project, labs are involved, but the reviewer always likes to see an industry partner with any project.

Presentation Number: elt216
Presentation Title: Isotropic, Bottom-Up Soft Magnetic Composites for Rotating Machines
Principal Investigator: Todd Monson (Sandia National Laboratories)

Presenter
Todd Monson, 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 and well-planned.

Reviewer 1:
This reviewer said that using iron nitride looks to solve the fundamental problem of access to rare-earth elements. It was not clear that the project has a good handle on the mechanical strength needed from the epoxy to hit 20,000 rpm. The reviewer asked if the new material will be evaluated based on a design that is optimized for this material; and if the 150°C temperature limit is the right limit for a motor design based on this material.

Reviewer 2:
The reviewer said the technical approach is feasible.

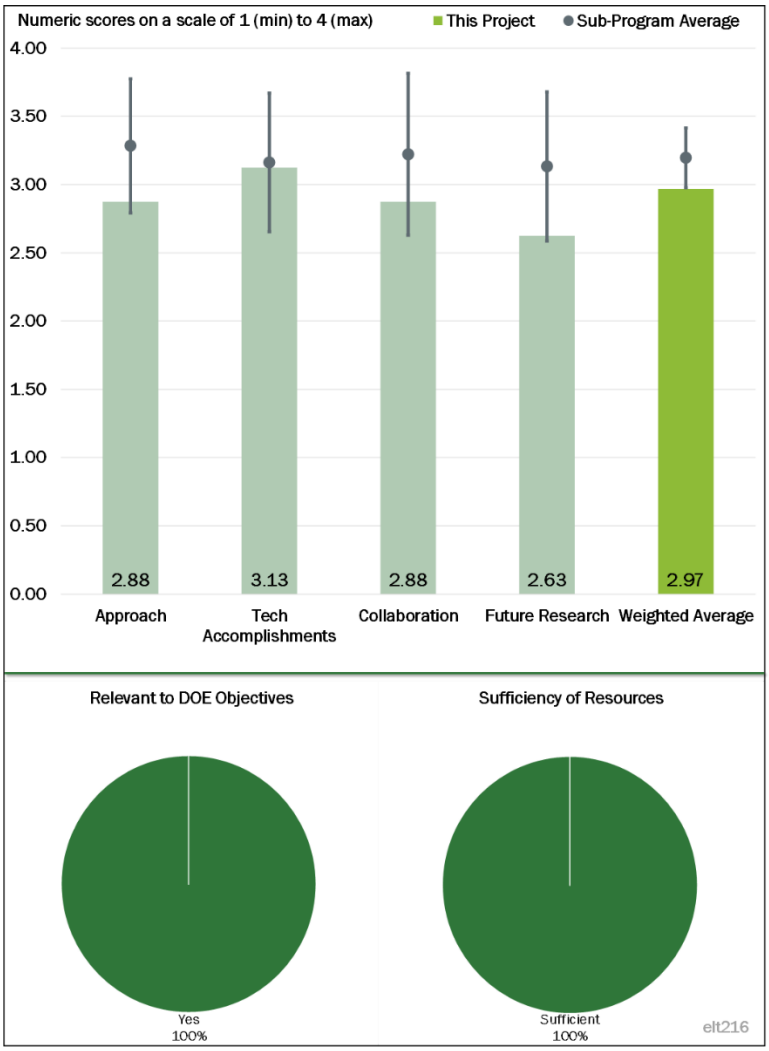

Figure 4-32 – Presentation Number: elt216 Presentation Title: Isotropic, Bottom-Up Soft Magnetic Composites for Rotating Machines Principal Investigator: Todd Monson (Sandia National Laboratories)

Reviewer 3:
This reviewer stated that soft magnetic composites (SMC's) have low iron loss at very high frequencies, usually above 100 kHz. The reviewer asked how advantageous SMC would be, because motors operate at much lower frequencies.

Reviewer 4:
It was not clear to this reviewer what the expected improvements with the developed materials are, compared to other soft magnetic composites that were previously developed. There is no need to spend resources on using the proposed composite material in a high-speed rotor. There are no obvious benefits from doing this.

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

Reviewer 1:
The reviewer said the presentation material showed good clear progress. It showed the ability to create the single-phase iron nitride and fabricate an inductor from, low core losses from this material, and the first step in the capability to put particles into epoxy. These seem like excellent steps toward the final goal.

Reviewer 2:
The reviewer stated that the progress is okay, but more comprehensive evaluation is needed.

Reviewer 3:
This reviewer stated that more evaluation of the first samples needs to be done. The reviewer asked if it is compatible with transmission oil, for application in motors that use transmission oil to cool the motor.

Reviewer 4:
The reviewer said quantification of the expected improvements in terms of the motor performance is needed. Also, a thorough comparison of expected properties relative to other SMC materials previously developed is needed.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer stated that the collaboration plan is feasible.

Reviewer 2:
The reviewer asked what the different is between the motor Illinois Institute of Technology (IIT) is designing and testing versus the motor Purdue is designing and testing. The reviewer asked if they have different power levels.

Reviewer 3:
This reviewer noted that the presenter mentioned collaboration, but it is hard to see it from the material. The reviewer asked if the PI can show any work element results from the collaborators, or are the collaborators just consulting.

Reviewer 4:
The reviewer said the level of collaboration needs to increase, especially when it comes to evaluating motor performance using the new proposed material.

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

Reviewer 1:
This reviewer said the presentation showed a good future approach to evaluate the mechanical properties, prove more than150°C glass temperature, and evaluate in a motor. It will be good to show that the motor design was optimized for this material. It will also be good to show the design analysis and stress analysis that shows the epoxy material has the strength to meet the motor requirements at more than20,000 rpm.

Reviewer 2:
This reviewer stated that more comprehensive evaluation is needed.

Reviewer 3:
The reviewer stated that mechanical strength is very important for a high-speed motor, and asked how it will be ensured. The reviewer also asked about temperature cycling and other environmental conditions such as humidity, ATF, storage, and process exposure.

Reviewer 4:
This reviewer referred to previous comments in terms of evaluating motor performance and not focusing on using the proposed material in a high-speed rotor unless there is a strong justification.

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

Reviewer 1:
This reviewer stated that eliminating scarce rare-earth elements in motors is in line with the DOE objectives to reduce cost while pushing power density.

Reviewer 2:
The reviewer said this project is relevant to DOE's goal to reduce the need for rare-earth materials.

Reviewer 3:
The reviewer said this material could provide low iron loss at higher operating conditions and reduce eddy current losses.

Reviewer 4:
The reviewer stated that this project is potentially relevant, but quantification of the expected benefits in terms of a motor design is needed.

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

Reviewer 1:
This reviewer said that based on the proposed scope, the resources seem sufficient.

Reviewer 2:
The reviewer commented resources are sufficient.

Reviewer 3:
The reviewer said the presentation material did not state the total project budget, so it is hard to tell.

Reviewer 4:
This reviewer asked who is going to help universities with motor sample build and testing, and who will build the laminations. The reviewer asked if the team is going to contract it out to a supplier.

Presentation Number: elt217
Presentation Title: Integrated/Traction Drive Thermal Management
Principal Investigator: Bidzina Kekelia (National Renewable Energy Laboratory)

Presenter
Bidzina Kekelia, 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 and well-planned.

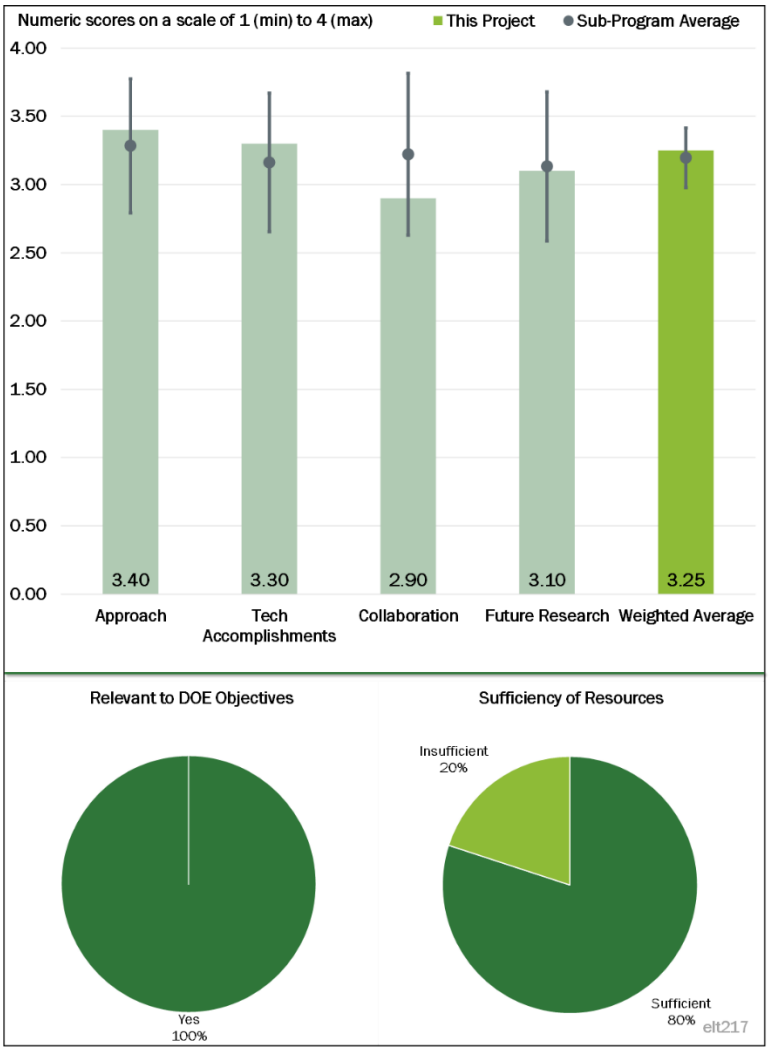

Figure 4-33 – Presentation Number: elt217 Presentation Title: Integrated/Traction Drive Thermal Management Principal Investigator: Bidzina Kekelia (National Renewable Energy Laboratory)

Reviewer 1:
The reviewer said the evaluation of a variety of coolants for electric motor and power electronics systems is a great approach. The adopted approach could have enough information by end of this project, which could lead to an adoption of the automatic transmission fluid (ATF)-based cooling technology for power electronics and electric motor assemblies.

Reviewer 2:
The reviewer stated that this approach is well thought out: first determine what has already been done; then determine the applicability to electric drive vehicles (EDVs); then find resources, test the hypothesis, create a model, and document the results.

Reviewer 3:
The reviewer said this is absolutely necessary work for providing thermal management guidelines on how best to integrate power electronics with the motor. The integration and cooling schemes simulated are all practical.

Reviewer 4:
This reviewer stated that jet impingement cooling is a good place to be looking at for improved thermal management. It is not clear that learnings from other applications of jet impingement have been identified. It is good to see the analysis and testing to complement each other.

Reviewer 5:
The reviewer said the stated work is good, but not really sure how it pushes the state-of-the-art/current knowledge. This is rather fundamental research, which may have been already accomplished.

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

Reviewer 1:
The reviewer noted that a lot of simulation results have been obtained. The findings on the effect of temperature on heat transfer coefficients are very useful.

Reviewer 2:
This reviewer noted good results from testing that show impact of some jet design parameters on the heat transfer coefficient. It would have been good to see a reference heat transfer coefficient for the typical cooling jacket design. It is not obvious how much better the jet impingement heat transfer coefficient is compared to current state-of-the-art.

Reviewer 3:
The reviewer noted that the heat transfer coefficients for the ATF based cooling systems has been evacuated over the temperature of the ATF and wide range of the nozzle velocity in the jet impingement. In this, ATF is directed to the hot spot in the electric motor such as end turns. CFD simulation of the jet orifice of ATF-based cooling system has been carried out. It looks like the necessary progress has been made in this project, which could lead to successful completion of the project.

Reviewer 4:
The reviewer said the jet impingent experiments results are interesting—as the surface temperature increases the convection coefficient increases. From a practical standpoint how could you take advantage of that in the electric motor? The project team is keeping with their schedule.

Reviewer 5:
The reviewer noted that progress has been achieved, however it is not clear what the contribution is to the existing heat transfer knowledge.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said the project team consists of an outstanding group of researchers who are highly experienced in thermal management of power electronics and electric motors.

Reviewer 2:
The reviewer said the project team is collaborating with OEM's to provide focus on their needs, and this is a good thing. Internally they are working to understand how to apply integrated cooling approaches into the motor, and this is also very good.

Reviewer 3:
The reviewer stated that the collaboration seems fine.

Reviewer 4:
This reviewer noted that OEMs and driveline fluid manufacturers, along with ORNL, are stated as collaborators. It would have been rather more beneficial to industries looking for the ATF-based cooling technology for power electronics and motor assemblies if the OEMs and driveline fluid manufacturers were identified by their names.

Reviewer 5:
The reviewer said this appears to be self-contained 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 relevant tasks are stated for future research, which seems appropriate and will be helpful in the successful completion of this project.

Reviewer 2:
This reviewer stated that the future work of testing other dielectric fluids in the same way they started with ATF could provide insights/improvements to motor cooling. Once these baselines have been established for the different dielectric fluids, it would be useful to evaluate long term fluid compatibility issues that might arise.

Reviewer 3:
The reviewer remarked that it is well-planned future work.

Reviewer 4:
This reviewer said it is a good approach to continue on to methods of integrating the impingement cooling into a motor design. It is not clear how much testing is needed versus analysis. The reviewer asked how much more testing is really needed if the jet impingement analysis agreed well with the testing. One place more work might be needed is on the impact of cross flow of coolant on impingement, once you put more than one jet next to each other. Analysis or testing in this area should be considered.

Reviewer 5:
The reviewer stated that this is expected, basic research. It fails to persuade this reviewer about the necessity of the current work.

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

Reviewer 1:
The reviewer stated that the results of this work would help the integration effort of miniaturizing electric drive systems, which is in direct alignment with the VTO ELT objectives for higher power density, lower cost, and higher reliability.

Reviewer 2:
The reviewer said this project supports high power motor and power electronics by improving the cooling capability of the high-power electronics.

Reviewer 3:
The reviewer said yes. ATF-based cooling technology, if demonstrated by example, could be very useful for industries in niche applications that require simplification of vehicle architecture.

Reviewer 4:
The reviewer said that the team's project impact statement says it all.

Reviewer 5:
The reviewer stated that the project is relevant, however more likely obvious results/outcomes.

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 simulation results and illustrations of experimental setup indicate that this project has the necessary resources for successful and timely competition.

Reviewer 2:
This reviewer stated that it appears the team is doing the work and providing results in a timely manner with the resources they have.

Reviewer 3:
The reviewer said that sufficient funding has been allocated.

Reviewer 4:
This reviewer said the resources seem sufficient.

Reviewer 5:
The reviewer stated that more resources would be needed for the team to do a good job on experimental validation.

Presentation Number: elt218
Presentation Title: Advanced Power Electronics Designs—Reliability and Prognostics
Principal Investigator: Doug DeVoto (National Renewable Energy Laboratory)

Presenter
Doug DeVoto, 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 and well-planned.

Reviewer 1:
The reviewer said the technical approach is clear and well-articulated.

Reviewer 2:
The reviewer stated that the approach addresses the critical need for predicting the lifetime of a vehicle power electronics system from interrelationships between package structures, materials, and physical models of mechanical, thermal, and electrical behaviors.

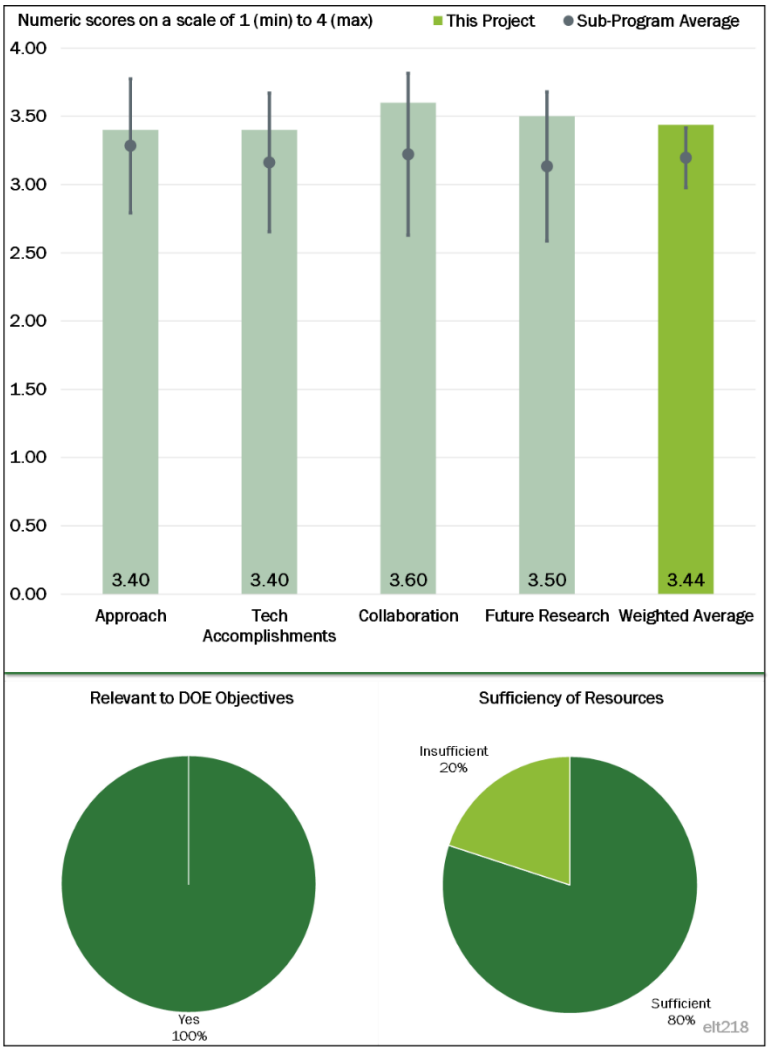

Figure 4-34 – Presentation Number: elt218 Presentation Title: Advanced Power Electronics Designs—Reliability and Prognostics Principal Investigator: Doug DeVoto (National Renewable Energy Laboratory)

Reviewer 3:
This reviewer said the approach for wire-bondless chip-to-chip interconnect technology looks very promising.

Reviewer 4:
The reviewer stated that the approach seems promising. However, more and various aggressive temperature conditions should be examined, and an economically optimized and reliable approach with proper size should be investigated further, rather than limited environmental conditions.

Reviewer 5:
The reviewer said the quilting approach is interesting, but from the slides it appears the technology is overlooking dual-sided cooled quilted power devices. The reviewer asked if quilting can be accomplished with a double-sided cooled power device. The results from the thermal aging, thermal shock, and power cycle look encouraging. Perhaps the project team could add bias humidity and operation life to the testing. The reviewer asked if the team can also quantify the number of interconnects between quilted die that are possible, and if the die need to be the same size and/or thickness to be quilted. The reviewer asked if the team can provide some data on the reliability of the quilted die approach.

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

Reviewer 1:
The reviewer remarked that this is outstanding progress in a short period of time! Extensive simulation efforts have been completed. Temperature-cycling results on an organic direct-bond copper (DBC) substrate material have been completed. Thermal performances of several types of substrates have been tested. A simulation framework for lifetime prediction has been established.

Reviewer 2:
The reviewer stated the project is on track with the planned schedule. Considerable simulation work has been developed to date, with the purpose of thermal evaluation of different packaging solutions.

Reviewer 3:
This reviewer observed that the device geometry is defined and the device is bonded on the substrate, which will be used for evaluation of interconnect reliability. The thermal impact of alternative DBC has been modeled, which could help selection of appropriate DBC material/type. A diode is bonded in DBC and DBC placed on cold-plate. This package is being used for thermal study such as thermal shocks, power cycling, etc.

Reviewer 4:
The reviewer noted that the project team appears to be on schedule, but if they take on additional testing this may slow them down. Their approach of modeling and testing is very good. Working with ORNL on a power module approach/design is excellent.

Reviewer 5:
The reviewer noted that this is a new project starting in 2019. The presented achievements and milestones are reasonable.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said that working with ORNL on a power module approach is outstanding. The power module is closer to what industry would use.

Reviewer 2:
The reviewer said the role of the different team members is clear, and their contributions are relevant to accomplish the project objectives.

Reviewer 3:
This reviewer remarked that all are highly qualified members for collaboration and teamwork.

Reviewer 4:
This reviewer said the collaborators and the roles of each party are well defined.

Reviewer 5:
This reviewer noted that ORNL, DuPont, and Indiana Integrated Circuits are identified and named as collaborators in the project, and project tasks have involved these partners.

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

Reviewer 1:
The reviewer stated the plan for future work is well articulated and the objectives stated are likely achievable in the planned timeline.

Reviewer 2:
This reviewer told the project team to continue the good work.

Reviewer 3:
The reviewer noted that thermal modeling of the developed packages has been identified as a future research task, which is quite relevant. Also, reliability of quilt package for thermal and power cycling has been stated as future research task. These tasks will be followed by study of half-bridge power module that uses chip-to-chip interconnects in the quilt-package, resulting in elimination of failure prone wire bonds.

Reviewer 4:
The reviewer stated the project appears to be on time, and their proposal for future work looks reasonable.

Reviewer 5:
The reviewer said the future research plans look reasonable and promising. The team should consider a more aggressive temperature environment and optimize the package based on the results. This should be considered in the future research.

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

Reviewer 1:
The reviewer said this project supports DOE objectives for increasing the power density of energy converters. The project focuses on thermal and reliability analysis.

Reviewer 2:
The reviewer said the project is directly aligned with the DOE VTO ELT objectives for low-cost and high-reliability power electronics in electric drives.

Reviewer 3:
The reviewer stated that the objectives outlined here match well with the priorities of DOE.

Reviewer 4:
This reviewer said yes, this project directly impacts, and possibly could improve, reliability of energy efficient WBG power electronics.

Reviewer 5:
The reviewer noted that the project team is focused on evaluating the new technology and how it applies to future power electronics application (lower cost, smaller size).

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

Reviewer 1:
This reviewer stated that the project has the necessary resources, technical, and supply chain related support from industry partners that will make this project a successful endeavor.

Reviewer 2:
The reviewer noted that the resources are commensurate with the goals, budget, and duration of the project.

Reviewer 3:
The reviewer said that the provided resources seem to be sufficient to support the execution of the project.

Reviewer 4:
This reviewer said that more funding would enable the team to carry out extensive experimental tests to validate the simulation and modelling efforts.

Reviewer 5:
They reviewer said that team members all appear to be working well together.

Presentation Number: elt219
Presentation Title: Power Electronics Materials and Bonded Interfaces—Reliability and Lifetime
Principal Investigator: Paul Paret (National Renewable Energy Laboratory)

Presenter
Paul Paret, 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 and well-planned.

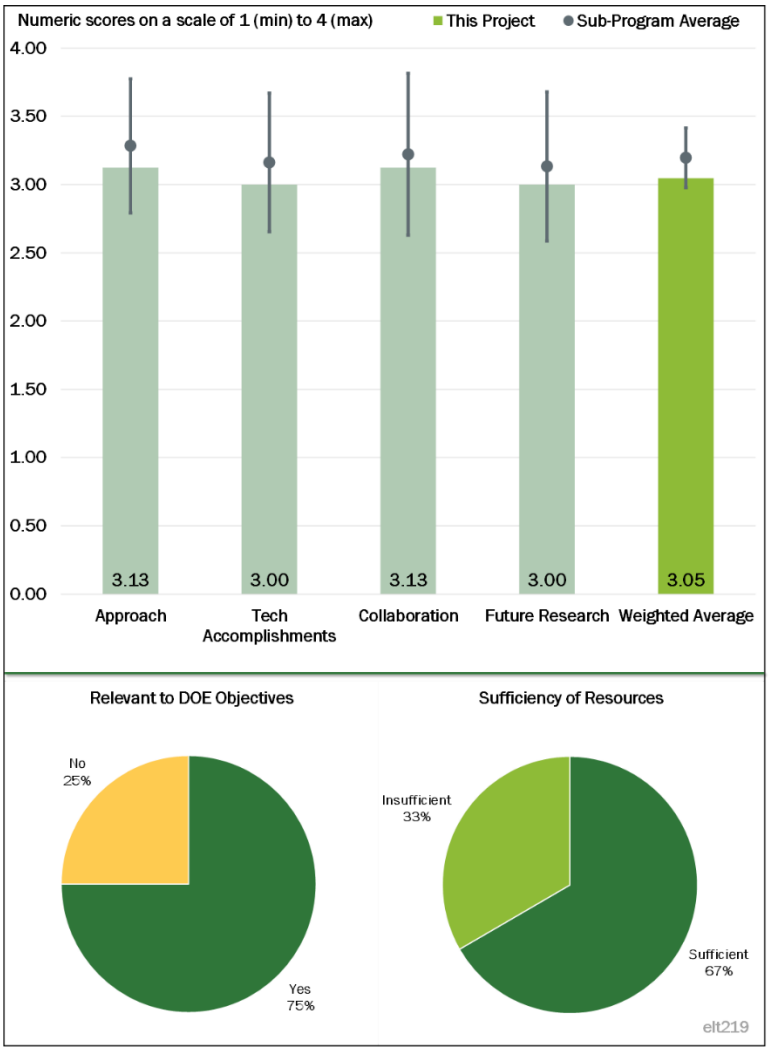

Figure 4-35 – Presentation Number: elt219 Presentation Title: Power Electronics Materials and Bonded Interfaces—Reliability and Lifetime Principal Investigator: Paul Paret (National Renewable Energy Laboratory)

Reviewer 1:
The reviewer stated that the technical approach is logical, comprising the synthesis of sintered silver bonds, followed by characterization, reliability evaluation, modeling for thermomechanical and lifetime behavior.

Reviewer 2:
The reviewer said the approach is sound and seems to address the required technology and challenges.

Reviewer 3:
This reviewer said it is important to compare new bonding solutions to a baseline of materials and processes commonly used in the industry today. This should include metrics that incorporate not only reliability and performance of the bonding technology, but also measures of the investment, cost, and processing time.

Reviewer 4:
The reviewer stated that the overall approach is sound, starting with a mechanical characterization of the material as a function of the processing, then moving on to evaluate reliability under accelerated conditions, then conducting FEA modeling to create a lifetime prediction model for the material under a variety of conditions. The choice of nano-silver, hybrid-silver, and copper-aluminum (Cu-Al) or copper-tin (Cu-Sn) transient liquid phase sintering (TLPS) as the materials was quite good. However, follow-on work should include other TLPS materials and nano-copper pastes. The use of -40°C to 200°C for the thermal cycling was also good as it captures failure that could occur when using SiC and other high temperature device technologies. The tasks and milestones are well defined.

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

Reviewer 1:
The reviewer said the performance to the stated objectives of the project have been met and appear to be on or ahead of schedule.

Reviewer 2:
This reviewer observed that despite the fact that the project is only beginning, significant progress has been made. Samples have been prepared and examined for each of the materials under a number of different processing conditions (for example, pressure and bond diameter) and characterized for voiding and cracking by C-mode scanning acoustic microscope (C-SAM) before and after temperature cycling. The mechanism of cracking was also determined.

Reviewer 3:
The reviewer noted that this project started in FY 2019, and the accomplishments achieved to date consist of early feasibility analysis.

Reviewer 4:
The reviewer said that this is a relatively new project and not much progress has been made.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said the role of the team members and collaboration are clearly explained.

Reviewer 2:
The reviewer said it seems that this project has a diverse and technically capable team. Coordination planning is in place.

Reviewer 3:
The reviewer said the team seems to be collaborating well internally. It is unclear what the interaction with industry (OEM, Tier 1/Tier 2, and raw material suppliers) is to ensure that solutions being explored are relevant and transferrable.

Reviewer 4:
The reviewer said there is good collaboration with the current university partners, but the collaborations could be extended to include additional universities and additional commercially available pastes. The role of ORNL is not clear nor are the identities of the "Private Industries."

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 future work is well defined and addresses the key barriers and challenges, as well as specifying additional work on materials such as sintered copper, and conducting more advanced theoretical fracture mechanics modeling.

Reviewer 2:
This reviewer said the future research is aligned with overall stated project goals. More relevance to addressing long term risks by incorporating relevant key life cycle testing would be useful.

Reviewer 3:
This reviewer said that based on the accomplishments achieved to date, it is unclear whether the remaining research challenges can be addressed. The presentation outlines six areas for future research, but there are no explanations on what approach the team plans to adopt to tackle each challenge.

Reviewer 4:
This reviewer would say that this research is not unique, in that several other bodies are researching similar fundamentals. The project has planned its work in a logical manner, and should be able to come to the proper conclusions.

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

Reviewer 1:
The reviewer stated that this project is relevant to overall DOE goals to enable energy efficient EV technology.

Reviewer 2:
This reviewer said the project has relevance in relating to WBG device packaging and smaller and higher power devices.

Reviewer 3:
This reviewer noted that packaging in general, and attachment fatigue in particular, is the source of many of the failures in power electronic systems. As such, understanding and mitigating attachment failure through proper materials selection and processing is critical to producing the reliable electronic systems needed for vehicle electrification.

Reviewer 4:
The reviewer said that from the presentation, it is unclear whether this project supports the DOE objectives. It seems focused on very fundamental studies on material synthesis, and does not provide indication of which applications could benefit from this research, and there is no quantification of its benefits (in terms of cost/weight reduction and reliability).

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

Reviewer 1:
This reviewer stated that the resources allocated for the project appear sufficient.

Reviewer 2:
The reviewer said the project funding level seems to be sufficient to achieve stated objectives.

Reviewer 3:
This reviewer said the small funding for this effort is sufficient for the current investigation because it can leverage the excellent experimental facilities at NREL, and the materials are donated by the universities. However, additional funding would allow this work to grow through the incorporation of more materials (e.g., TLPS, commercially available pastes) and more test conditions (e.g., power cycling), therefore, providing even more options for the design of reliable power systems.

Reviewer 4:
In this reviewer's opinion, $175,000 is not adequate to cover the work required for this project.

Presentation Number: elt220
Presentation Title: Ultraconducting Copper
Principal Investigator: Tolga Aytug (Oak Ridge National Laboratory)

Presenter
Tolga Aytug, Oak Ridge 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 and well-planned.

Reviewer 1:
The reviewer said the proposed approach seems good even though there are several risks and challenges.

Reviewer 2:
The reviewer said the overall approach is okay, but all operating conditions such as compatibility with ATF oil, varnish, and manufacturability must be studied.

Reviewer 3:
This reviewer remarked that it is unclear why an extremely complicated and potentially expensive CNT/Cu hybrid material is relevant for EV applications. The improvement in thermal and electrical properties, as well as reliability and recyclability, just seem to not justify a change in conductor design.

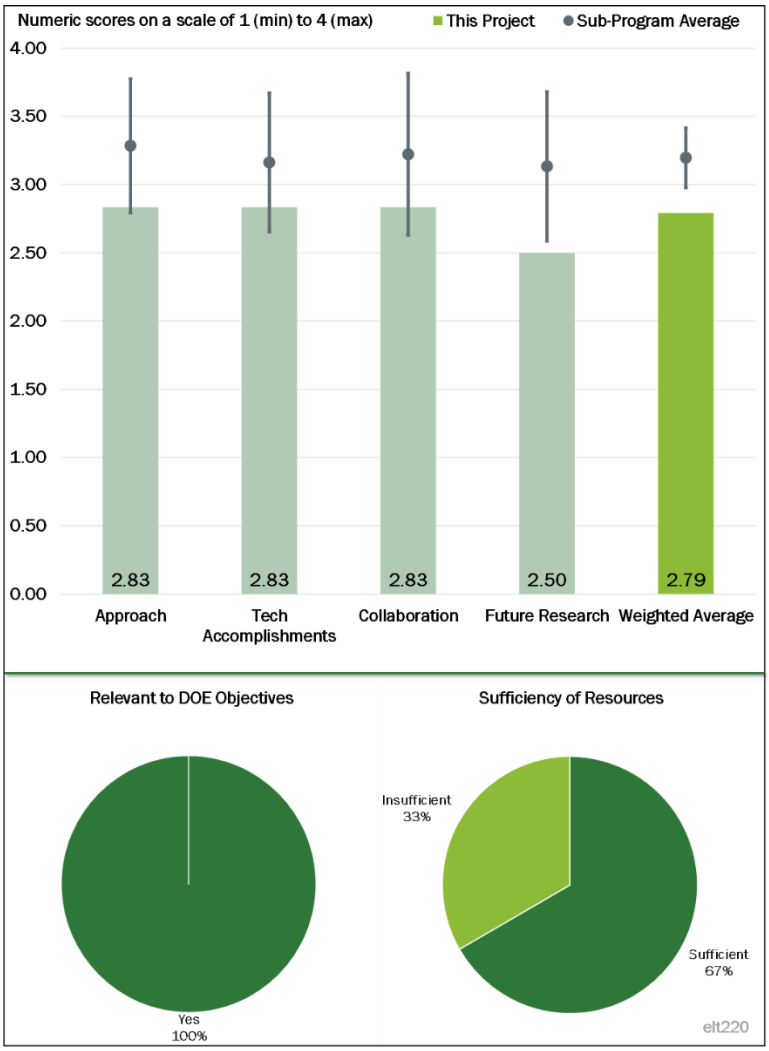

Figure 4-36 – Presentation Number: elt220 Presentation Title: Ultraconducting Copper Principal Investigator: Tolga Aytug (Oak Ridge National Laboratory)

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

Reviewer 1:
The reviewer noted that the project is on track to achieving its stated goals.

Reviewer 2:
This reviewer said there is good progress, but the issue of reduced effectiveness of added CNT layers need to be resolved

Reviewer 3:
This reviewer noted that the samples have been built, but test results are not meeting full expectations. If the process of making this conductor is too complicated and the cost is much higher than copper, then meeting DOE cost targets is questionable.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said there seems to be good collaboration with external entities as well as internally within ORNL in terms of evaluating the impact of the improved Cu properties on the motor performance.

Reviewer 2:
The reviewer stated that the team appears to be collaborating, but discussions with the PI indicate that some relevant technical details, such as benchmark performance, have not been effectively communicated in detail between team members.

Reviewer 3:
The reviewer said that a motor manufacturer should have been a partner. Forming the cut wires and soldering them is very important for motor manufacturing.

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

Reviewer 1:
The reviewer said the proposed work is good and try to address the current challenges.

Reviewer 2:
This reviewer stated that developing the concept of high conducting material is the first step, but design for manufacturability must be always considered.

Reviewer 3:
This reviewer observed that the future decision points and research do not take into account the actual relevance of this solution to industry, especially the significant risks of trading off cost/complexity with moderate proposed improvement in properties.

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

Reviewer 1:
The reviewer said that if successful in significantly increasing the conductivity of copper, this can have a significant impact on improving the motor power density.

Reviewer 2:
The reviewer noted that the project is relevant to DOE's technical barriers, but the approach is quite a longshot and will likely find a difficult adoption path with industry.

Reviewer 3:
The reviewer said it is in alignment with reducing the motor size, but it is not in alignment with reducing the cost of the motor.

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

Reviewer 1:
This reviewer said that based on the proposed scope, the resources seem sufficient.

Reviewer 2:
This reviewer said the project is not funded at a very high level, which seems appropriate for a highly speculative approach to improving wire properties.

Reviewer 3:
The reviewer stated that to develop the concept material $150,000 may be okay, but to investigate the feasibility of making a motor with this material the funding is not sufficient.

Presentation Number: elt221
Presentation Title: Integrated Electric Drive System
Principal Investigator: Shajjad Chowdhury (Oak Ridge National Laboratory)

Presenter
Shajjad Chowdhury, Oak Ridge National Laboratory

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

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

Reviewer 1:
The reviewer stated that this is a review of existing know-how and reports, followed by simulation and prototyping to obtain power-dense drivetrain system—it looks like an appropriate approach for this project.

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

Reviewer 1:
The reviewer said that this is a very good literature survey and utilization optimization of available resources.

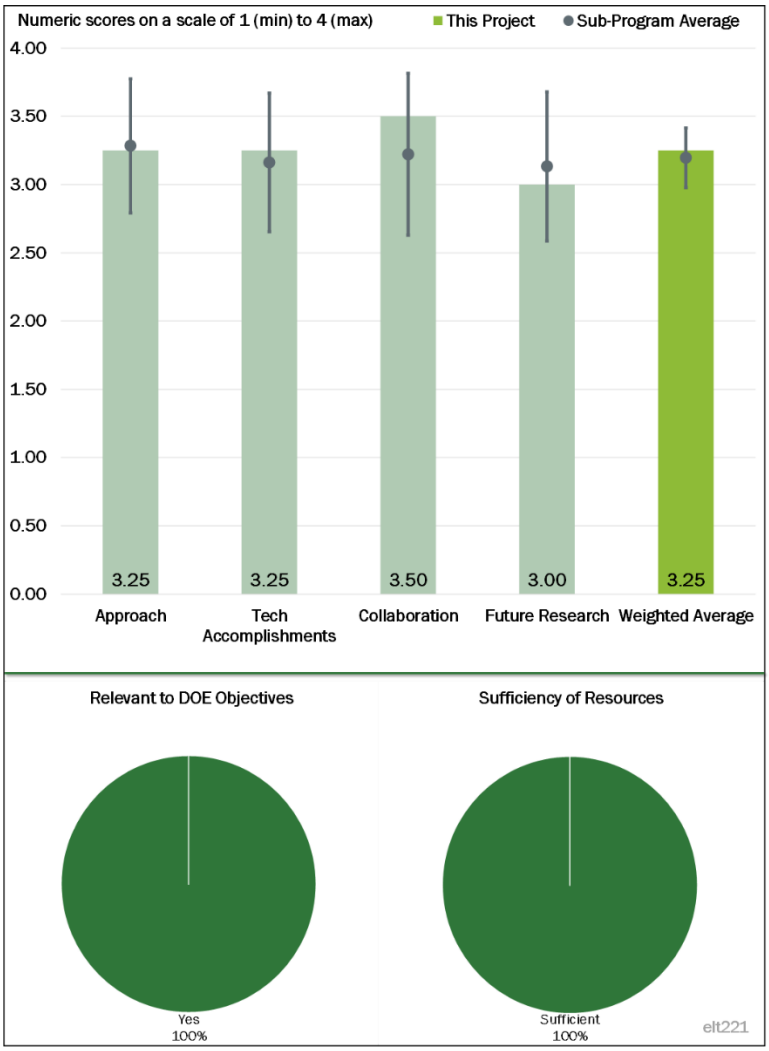

Figure 4-37 – Presentation Number: elt221 Presentation Title: Integrated Electric Drive System Principal Investigator: Shajjad Chowdhury (Oak Ridge National Laboratory)

Reviewer 2:
The reviewer noted that the parts that could go to higher temperatures have been identified for an integrated assembly of drivetrain system that combines power electronics with electric machine. Inverter motor topology has been selected for thermal analysis. Inverter losses are estimated and torque-speed profile of drivetrain system simulated and illustrated in the project report. Model for thermal evaluation has been developed. Radial mount (on motor housing) inverter system is designed for thermal analysis. CeraLink capacitor's temperature profile evaluated to get 150°C operation. The reviewer highlighted that the DC bus capacitor can be located close to slots, as per project report, which is quite unique.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted that four DOE National Laboratories are involved in this project. This reviewer encourages the project PI to get industry collaboration in place as soon as possible.

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

Reviewer 1:
The reviewer said the relevant tasks are outlined in the project report.

Reviewer 2:
The reviewer noted that validation of system losses are not clearly defined: Inverter, motor…it is essential to validate analytically as already done and empirically when hardware is available.

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

Reviewer 1:
The reviewer said that this is in line with the DOE target for power density increase.

Reviewer 2:
The reviewer stated that this project is quite relevant, as EVs need integrated drivetrain systems that is in a single assembly similar to that proposed by this project. Therefore, successful completion of this project with prototype parts available for show-and-tell could support U.S. industries and encourage them to adopt the developed technology, particularly when the supply-chain for required parts is identified and developed through 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 stated that the tasks completed so far indicate that this project is resourced necessary and sufficiently.

Reviewer 2:
This reviewer said there is no evidence for missing or excessive resources.

Presentation Number: elt222
Presentation Title: High-Reliability Ceramic Capacitors to Enable Extreme Power Density Improvements
Principal Investigator: Jack Flicker (Sandia National Laboratories)

Presenter
Jack Flicker, 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 and well-planned.

Reviewer 1:
The reviewer stated that the overall approach is straightforward. No issues with experimental plan noted.

Reviewer 2:
This reviewer said that ceramic capacitors are rapidly replacing metallized film, aluminum electrolytic, and solid tantalum capacitors in power electronic systems. Finding ways to improve their performance and reliability is critical to next-generation vehicle electronics. Improving the capacitor lifetime through investigating and mitigating the presence of oxygen vacancies, as opposed to modifying the material composition or microstructure, is a novel approach that is sound theoretically and interesting practically.

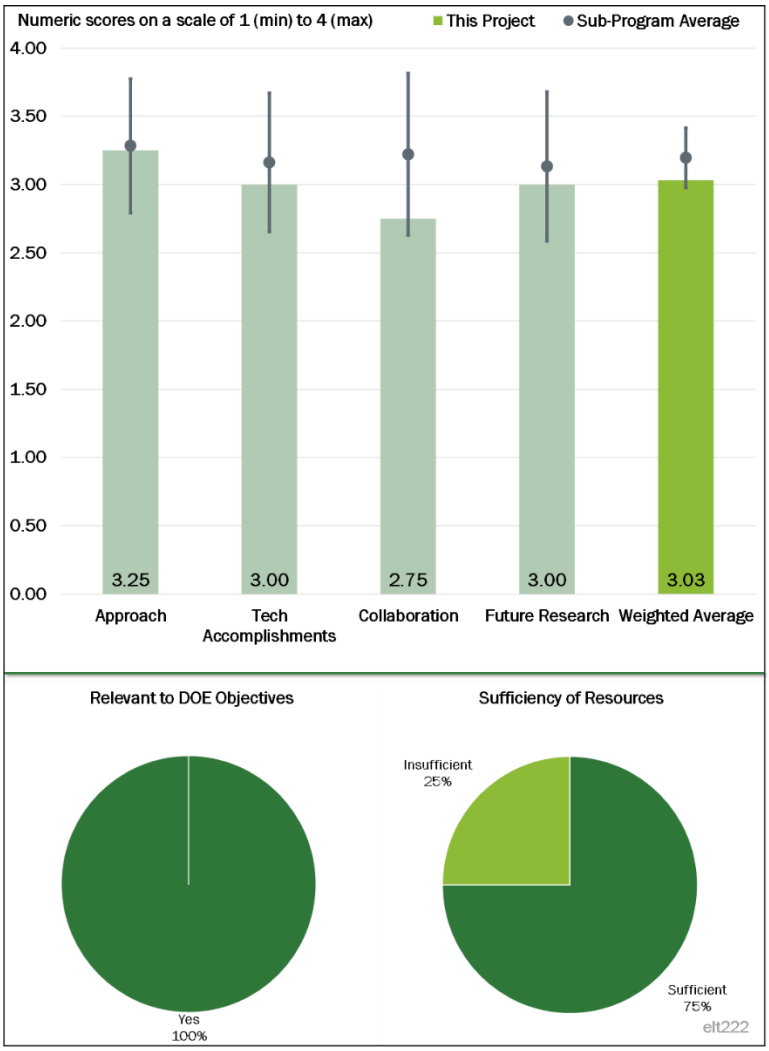

Figure 4-38 – Presentation Number: elt222 Presentation Title: High-Reliability Ceramic Capacitors to Enable Extreme Power Density Improvements Principal Investigator: Jack Flicker (Sandia National Laboratories)

Reviewer 3:
The reviewer noted that this project starts by outlining challenges to current capacitor technology, one of which is high cost. This aspect, however, is not addressed at all in the following slides. Technically, this is a very interesting approach, however, more clarity is needed on this approach to address the target outlined.

Reviewer 4:
The reviewer stated that the presenter appears to be solving a problem without a full understanding of the application. The presenter understands that adding bipolar switching to extend the life of the capacitor may be an issue with cost and complexity of the inverter. The presenter should also be considering other issues with respect to the inverter and how that may affect the capacitor. For example, in today's automotive inverters, direct current (DC)-link capacitors require benign failure. It is not clear to the reviewer if the ceramic cap he is

pursuing will comply with the self-healing capability. This reviewer would suggest he take a step back and discuss with the OEM's what the requirements are for the DC link capacitor used in inverters today.

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

Reviewer 1:
This reviewer said that good progress has been made so far on the technical achievements, but a more holistic approach is needed to satisfy other aspects.

Reviewer 2:
This reviewer stated that the accomplishments have been limited due to limited time and funding ($0), but capacitor degradation under DC bias, and bipolar switching at different frequencies has been examined and the preliminary results are encouraging. The project team have shown a 4X increase in lifetime with 2.5 Hz switching versus DC bias, providing evidence that this oxygen vacancy mitigation approach may be a viable way to improve life.

Reviewer 3:
The reviewer said the project may have benefited by starting with a benchmarking of current industry practice and hardware to understand if capacitor failure is a significant issue for OEMs.

Reviewer 4:
The reviewer said this is a new start and the presenter has ideas of what is needed, but has not looked deep enough to see what already has been done. It would be helpful if the problem could be better defined. In other words, for a given switching range and ripple voltage, what range of capacitance and equivalence series resistance (ESR) would be required.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted that complementary capabilities have been identified through NREL and Oak Ridge National Laboratory. Not much collaboration so far—it is expected to pick up.

Reviewer 2:
The reviewer said the level of coordination and collaboration between the partners was not clear from the work presented, although the work to-date did not require high levels of coordination.

Reviewer 3:
This reviewer observed that the collaboration is only within the National Laboratories and the roles of the National Laboratories other than the Prime (Sandia) is not clear. It is hoped that this collaboration will increase with additional time and funding.

Reviewer 4:
The reviewer suggested that the presenter needs to discuss requirements with the OEMs or others in automotive to better understand what is done in the transportation sector. Today the presenter is suggesting the use of a ceramic cap, but at the same time the presenter is proposing solving issues with that technology before he understands the application requirements. Perhaps some time should be spent determining what the best technology is for the application, and stating why. There is an Advanced Research Projects Agency-Energy (ARPA-E) charger program that is proposing using a film cap for the same reasons the presenter is choosing a ceramic cap (power density)—the application noted will be at the ARPA-E summit and may be of interest.

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 proposed future research is very well outlined.

Reviewer 2:
The reviewer said the future research proposed by the team seems to address some of the key issues that would be relevant to risk mitigation of capacitor failure. More details on future research plans would be appreciated so that reviewers could better evaluate and provide feedback on relevance of the proposed work.

Reviewer 3:
This reviewer said that more detail is needed on the types of capacitors and types of testing that are anticipated in future years of this effort and why those types of capacitors and tests are chosen to demonstrate oxygen vacancy degradation. In addition, more substantial theoretical modeling needs to be conducted to link the hypothesized failure mechanism (i.e., oxygen vacancy transport) to the level of degradation observed during switching at different frequencies.

Reviewer 4:
The reviewer said that complicated bipolar switching may be incompatible with low-cost drive. The presenter understands there is a cost challenge with what he is proposing. That is a good start for future work.

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

Reviewer 1:
This reviewer said that power electronics reliability is a key barrier to adoption of EVs, and therefore is relevant to overall DOE goals.

Reviewer 2:
The reviewer noted that because of increased reliability, higher temperature operation, better temperature stability, and a reduction in the required capacitance in high frequency applications, ceramic capacitors are rapidly replacing metallized film, aluminum electrolytic, and solid tantalum capacitors in power electronic systems. In fact, ceramic capacitors share of the worldwide capacitor market has grown from 35% to 65% in the last ten years. Finding ways to use these capacitors reliably in vehicle electronics is critical to meeting the DOE targets for efficiency, power density, and cost in next generation electric vehicles.

Reviewer 3:
The reviewer said that achieving power electronics density will require improvements in all aspects of drive train (switches, passives, etc.). The above is correct, higher power density equals smaller inverters, which equals more packaging options for the OEM, which equals lower cost/system due to higher volumes, which equals helping to enable wider adoption of EDVs.

Reviewer 4:
The reviewer stated that the project supports device miniaturization to achieve high power density by switching to passive components that are more efficient.

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 that the resources seem adequate to meet the stated objectives of the project.

Reviewer 2:
The reviewer said the resources are sufficient.

Reviewer 3:
The reviewer said that while the current unfunded effort has generated preliminary experiments demonstrating that oxygen vacancy transport could be responsible for different levels of degradation in capacitors switched at different frequencies, substantially more funding is needed to do a full study of this effect on a wider range of capacitors, including additional theoretical modeling, analysis, and validation testing.

Reviewer 4:
This reviewer said it would be helpful to discuss the application with an OEM(s) or Tier 1 supplier to better understand the application requirements.

Presentation Number: elt223
Presentation Title: Component Testing, Co-Optimization, and Trade-Space Evaluation
Principal Investigator: Jason Neely (Sandia National Laboratories)

Presenter
Jason Neely, Sandia National Laboratories

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 and well-planned.

Reviewer 1:
This reviewer said that system-wide optimization of power semiconductors, power converters, and motors is important for meeting the DOE 2025 performance and cost metrics. More information on the test-bed(s) (planned or existing) and its capabilities would be appreciated. Additional detail about the level of detail captured by the reduced-order metamodels would also be appreciated.

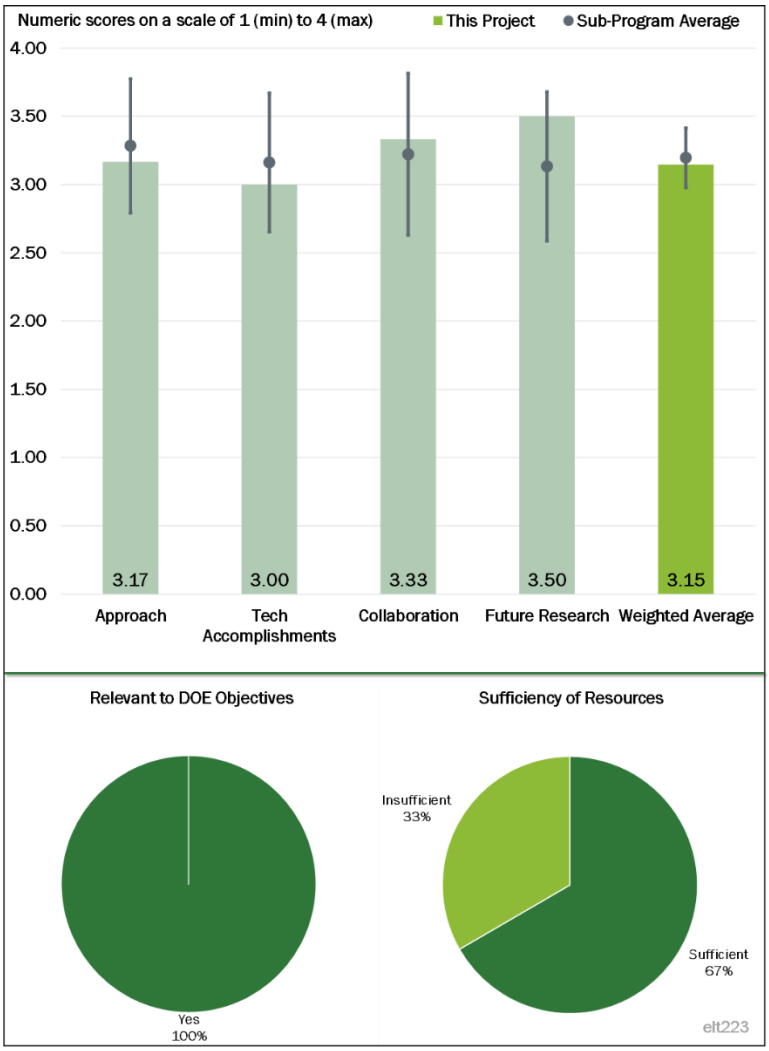

Figure 4-39 – Presentation Number: elt223 Presentation Title: Component Testing, Co-Optimization, and Trade-Space Evaluation Principal Investigator: Jason Neely (Sandia National Laboratories)

Reviewer 2:
The reviewer said this project is very relevant and an excellent project for the DOE, unfortunately the first application may be more into aerospace.

Reviewer 3:
This reviewer said that it is not clear how this approach is an advancement from the current state-of-the-art. The reviewer asked what new techniques or technologies will be investigated, and why the custom test bed is needed.

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

Reviewer 1:
This reviewer noted well-defined accomplishments. Please continue this project!

Reviewer 2:
This reviewer suggested leveraging already existing SAE and OEM performance and reliability standards for power semiconductors. This would be useful to integrate with any Sandia National Laboratories-developed

performance criteria. Some of the performance of the power converter is very much going to depend on the layout of the devices and the converter. The reviewer asked if this level of detail will be captured.

Reviewer 3:
This reviewer said that some progress was shown in design tradeoffs. No progress was shown in the development of the custom test bed.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said this project has an excellent level of collaboration.

Reviewer 2:
The reviewer noted that this project showed work elements from Purdue University in the presentation material. Looks like good organization of work across collaborators.

Reviewer 3:
This reviewer said that the project is just beginning. It is difficult to evaluate the collaboration so far.

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 moving towards an optimized electronics and machine design is a good approach and it looks like the work is being planned to make it.

Reviewer 2:
The reviewer stated that system wide and sub-system optimization is very important to reaching overall DOE objectives.

Reviewer 3:
This reviewer said that VTO needs to continue this project—the reviewer can see a high impact here.

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

Reviewer 1:
This reviewer said the project is relevant to the overall DOE objectives. Establishing the power device performance and reliability criteria is also important.

Reviewer 2:
The reviewer stated that an approach to design a smaller, well-integrated electronics package will help the DOE objectives for size of electronics components.

Reviewer 3:
This reviewer said yes, inverters are necessary 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 resources seem to be sufficient.

Reviewer 2:
This reviewer noted that if additional funds could be provided here, this is a very relevant and promising project.

Reviewer 3:
This reviewer said it is not clear how much money is allocated for future years. $250,000/year does not sound like enough to do custom test bed development, and design and prototyping of power electronics, and a machine.

Presentation Number: elt234
Presentation Title: Soft Magnets to Achieve High-Efficiency Electric Drive Motors of Exceptional Power Density
Principal Investigator: Matthew Kramer (Ames Laboratory)

Presenter
Matthew Kramer, Ames Laboratory

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

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

Reviewer 1:
The reviewer stated that this project aims at developing a new casting process to synthesize alloy steels with high Si content. The proposed approach is effective and well-articulated, with clear partitioning into tasks and a precise schedule and milestones.

Reviewer 2:
This reviewer said the main accomplishment is the demonstration of the planar flow casting system for this budget period, with the Fe-6.5% Si alloy. The major concern is if the process can scale beyond the proposed 25 mm width strip. For useful strip widths it will need to be wider even for segmented motor production. It would have been useful to measure some of the mechanical properties of the 6 mm before moving to the wider strip.

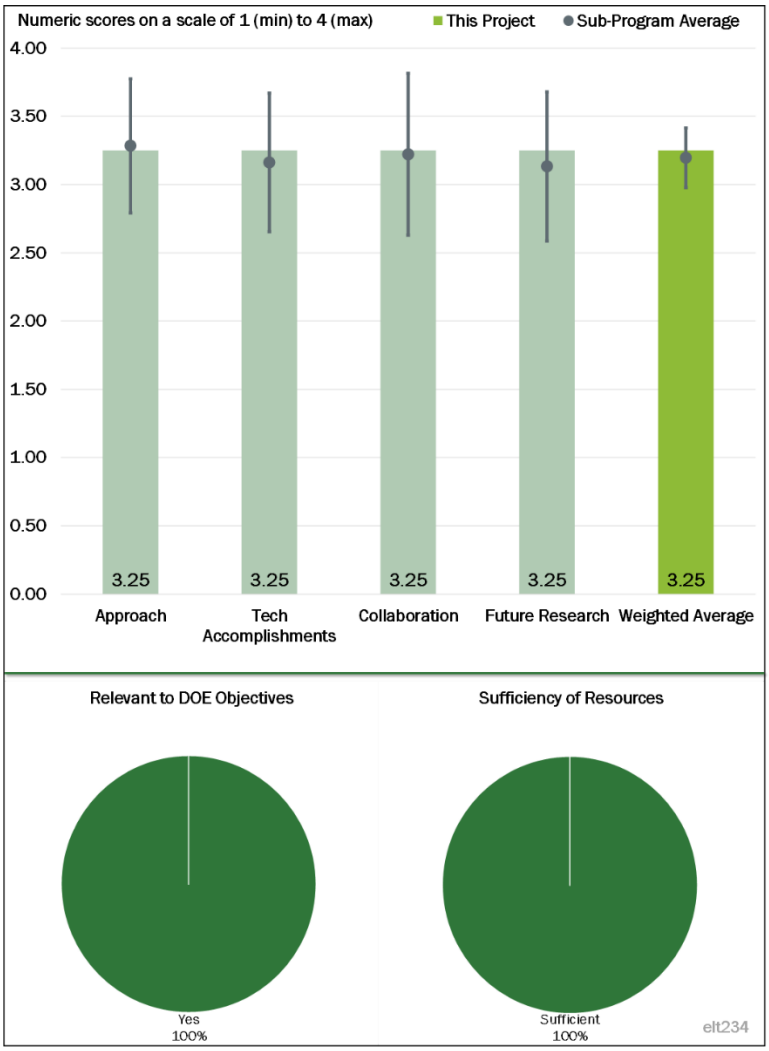

Figure 4-40 – Presentation Number: elt234 Presentation Title: Soft Magnets to Achieve High-Efficiency Electric Drive Motors of Exceptional Power Density Principal Investigator: Matthew Kramer (Ames Laboratory)

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

Reviewer 1:
The reviewer noted that the project has already demonstrated the planar flow casting system, which addresses one of the two key technical challenges envisioned for this project. In this sense, the project appears well on track with respect to proving the feasibility of the casting process.

Reviewer 2:
This reviewer asked why the reported Fe loss of the spun ribbon (12.3 W/kg) [Slide 8] is much worse than the predicted loss of 5.7 W/kg [Slide 5]. The reviewer asked if that is for the 0.33 mm strip thickness. The measured loss is not much better than the 3.2% Si steel. The reviewer asked if the magnetization properties were beyond the core loss tested, and about saturation and permeability. The reviewer asked how the

researchers propose to grow the large grain sizes, and if any mechanical property measurements been made on the smaller width demonstration strip.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted that the project team is composed by four members, each responsible for key technical tasks. The distribution of tasks across team members is well balanced and commensurate with the expertise of each organization.

Reviewer 2:
This reviewer said it is not clear that all project partner National Laboratories have been involved 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:
This reviewer noted that the future research challenges are carefully planned and are consistent with the end goals of the current project. A few more details should be given on how the team plans to address the technical challenges envisioned for future research.

Reviewer 2:
The reviewer wished that a more detailed project plan for the future had been included.

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

Reviewer 1:
The reviewer said development of a low-loss and ductile Fe-6.5% Si alloy suitable for volume motor production beyond the chemical vapor deposition based JFE supercore is a project goal that supports the DOE objectives.

Reviewer 2:
The reviewer said the project focuses on synthesizing soft magnetic materials suitable for non-rare-earth element electric motors with high power density. In this sense, the project responds directly to one of the key DOE goals.

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

Reviewer 1:
The reviewer said the resources appear to be appropriate.

Reviewer 2:
The reviewer stated that the resources and personnel allocated to the project are sufficient.

Presentation Number: elt235
Presentation Title: Behind-the-Meter Storage Overview
Principal Investigator: Anthony Burrell (National Renewable Energy Laboratory)

Presenter
Anthony Burrell, National Renewable Energy 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 and well-planned.

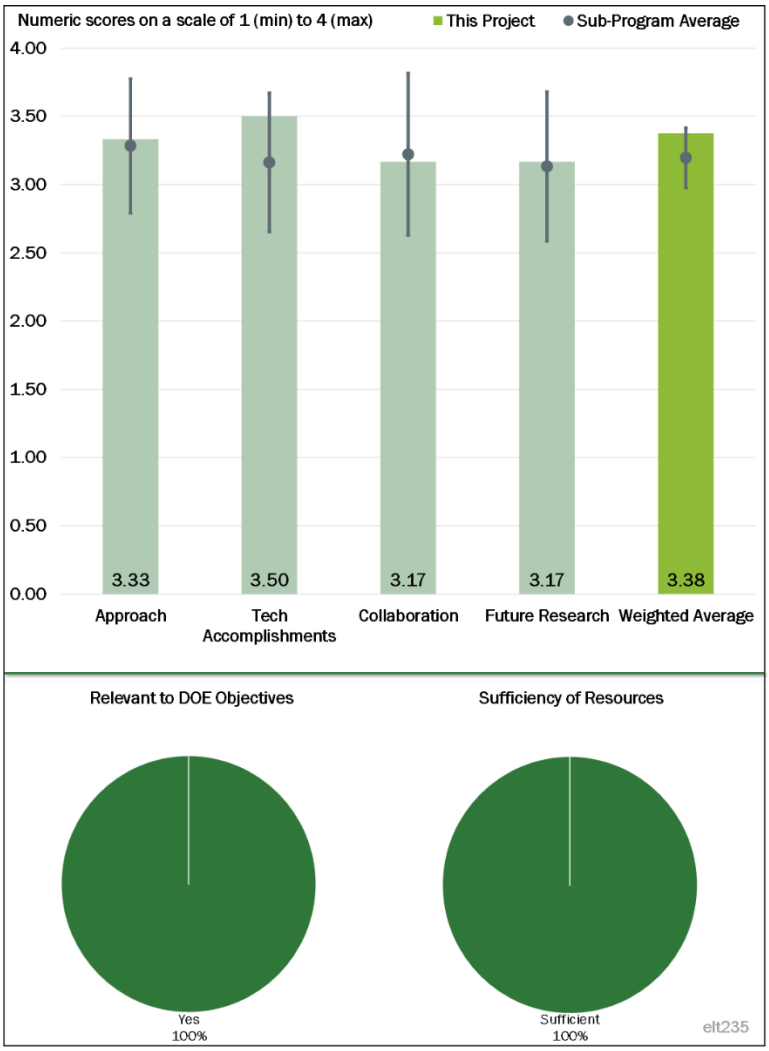

Figure 4-41 – Presentation Number: elt235 Presentation Title: Behind-the-Meter Storage Overview Principal Investigator: Anthony Burrell (National Renewable Energy Laboratory)

Reviewer 1:
The reviewer said this project is very important. It is great to see work across the various sectors of DOE. Task 1, Development of metric and targets—the reviewer sees this as critical. Very pleased to see this is front and center of this effort. Please incorporate as much industrial input as possible in this section of the project. The reviewer remarked Task 2, Behind the Meter Storage (BTMS) Test Procedure Development and Verification is also critical to the success of this project. Great to see this called out. Task 3, Battery Material and Cell Design – the reviewer appreciated that the needs of BTMS are different from that of automotive. The reviewer encouraged the project to explore existing chemistries that may have also been overlooked, before going after new materials.

Reviewer 2:
The reviewer stated that this project is well-designed to determine the metrics and targets for energy storage using system modeling approach. The reviewer suggested including more electrochemical energy storage options using abundant materials.

Reviewer 3:
The reviewer said this is a very ambitious but much needed program, which will help define and bound the stationary storage sector. Key considerations such as removal of critical materials from stationary storage systems will allow transportation and stationary technologies to thrive without the need to compete for the same scarce materials or supply chains. Approach to leverage thermal storage with battery storage is unique, and the technologies should be quite complimentary.

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

Reviewer 1:
The reviewer said the technical accomplishments are outstanding considering the projects have just started last year.

Reviewer 2:
This reviewer said that defining the ecosystem for BTMS, like any new endeavor, has proved challenging. However, given the short time this project has been active, the team has shown great progress. Well-defined tasks rooted in DOE technical targets as well as industry requirements have been established. Determination of baseline system design and parameters/considerations will be needed before the project can pursue laboratory testing and materials discovery.

Reviewer 3:
The reviewer stated that this project is very important. It is great to see work across the various sectors of DOE. Task 1, Development of metric and targets—the reviewer sees this as critical and is very pleased to see this is front and center of this effort. Please incorporate as much industrial input as possible in this section of the project. Task 2, BTMS Test Procedure Development and Verification is also critical to the success of this project. Great to see this called out. Task 3, Battery Material and Cell Design—the reviewer appreciated that the needs of BTMS are different from that of automotive. The reviewer encouraged the project team to explore existing chemistries that may have been overlooked, before going after new materials. Please consider inexpensive $LiFePO_4$ cells that are optimized for your requirements, not ultrahigh power. The cells are very cheap and at the same time capable of meeting up to 10,000 cycles (depending on exact cycling conditions). This $LiFePO_4$ is not the expensive nano, heavily architectured $LiFePO_4$ that most people in the U.S. academic environment think of. The particle size is bigger and is very cheap to make. The cell format being used could also be important. Please consider metal prismatic hardcase as the format. This cell format allows for long life due to the great sealing that prevents moisture permeation (unlike pouch or cylindrical). The reviewer said it might also be necessary to think about a service step, where for example additional electrolyte might need to be added (and gasses removed) after 10 years in order to achieve your 20 year calendar life goal. Cycle life should not be a problem for a properly designed and manufactured cell. The reviewer is intrigued by the concept of machine learning. The reviewer saw the value in optimizing the use of the battery by taking into account the various tradeoffs so that a 20-year life can be reached. Life models are critically important. The reviewer is glad to see that a physics-based approach will be used.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
This reviewer said the planning looks good—let us see how the project develops.

Reviewer 2:
The reviewer noted that this is a large project team consisting of National Laboratory experts in each proposed field. The reviewer suggested the team engage with industry on use cases and technology trends to help bound and guide assumptions and technical targets. An independent industry review board may be a useful tool to ensure the project stays on track and remains relevant.

Reviewer 3:
This reviewer said the contribution from some partners is not so clear, but it is acceptable at this stage considering the project is only getting started. The reviewer hoped it will become clearer going forward.

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 team is pursuing many research topics from existing material characterization and testing to new material discovery, and system integration to cost modeling. Focusing the project team on achieving all outlined objectives will be challenging. However, the project team is large and comprised of experts in each field.

Reviewer 2:
The reviewer noted that the project just started, and referenced prior comments.

Reviewer 3:
This reviewer stated that better analysis needed to support some of the conclusions and should be proposed as future work. For example, "Vehicle batteries will not necessary be the answer to long term storage requirements" is not supported by the previous system modeling. Future work for Battery Storage Technology R&D should be more clearly aligned with using non-critical materials for energy storage.

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

Reviewer 1:
The reviewer stated that BTMS could be the critical component that enables the goals of VTO, Solar, and Building Efficiency. It is great to see this work funded.

Reviewer 2:
The reviewer said this project supports the overall DOE objectives. It targets the development of innovative critical-material-free energy storage technologies to minimize the need for significant upgrades to the electric grid and eliminate excess demand charges that EV fast charging would incur using existing technologies. This will improve grid resilience and make the United States energy independent.

Reviewer 3:
This reviewer said the removal of critical materials from BTMS systems serves the DOE objectives of national security and avoidance of material supply chain scarcity.

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 Laboratory team has state-of-the-art facilities, which are more than adequate to carry out the tasks defined in this project. The funding levels are commensurate with the scope and depth of research needed to achieve the technical targets.

Reviewer 2:
The reviewer stated that the resources are sufficient.

Reviewer 3:
This reviewer said the resources appear to be sufficient at this point, but should be reexamined as work progresses.

Presentation Number: elt239
Presentation Title: High-Power Inductive Charging System Development and Integration for Mobility
Principal Investigator: Omer Onar (Oak Ridge National Laboratory)

Presenter
Omer Onar, Oak Ridge 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 and well-planned.

Reviewer 1:
The reviewer said the approach is solid, well thought out, methodical, and incremental. Decision points allow for off-ramps should the technology not meet the goals.

Reviewer 2:
The reviewer said the project team has laid out a clear approach—design, model, simulate, and analyze the system, then integrate and validate the initial 100 kW system, and finally refine the initial system and integrate/validate the 300 kW system. This seems pretty straightforward, and designed to accomplish the project's goals.

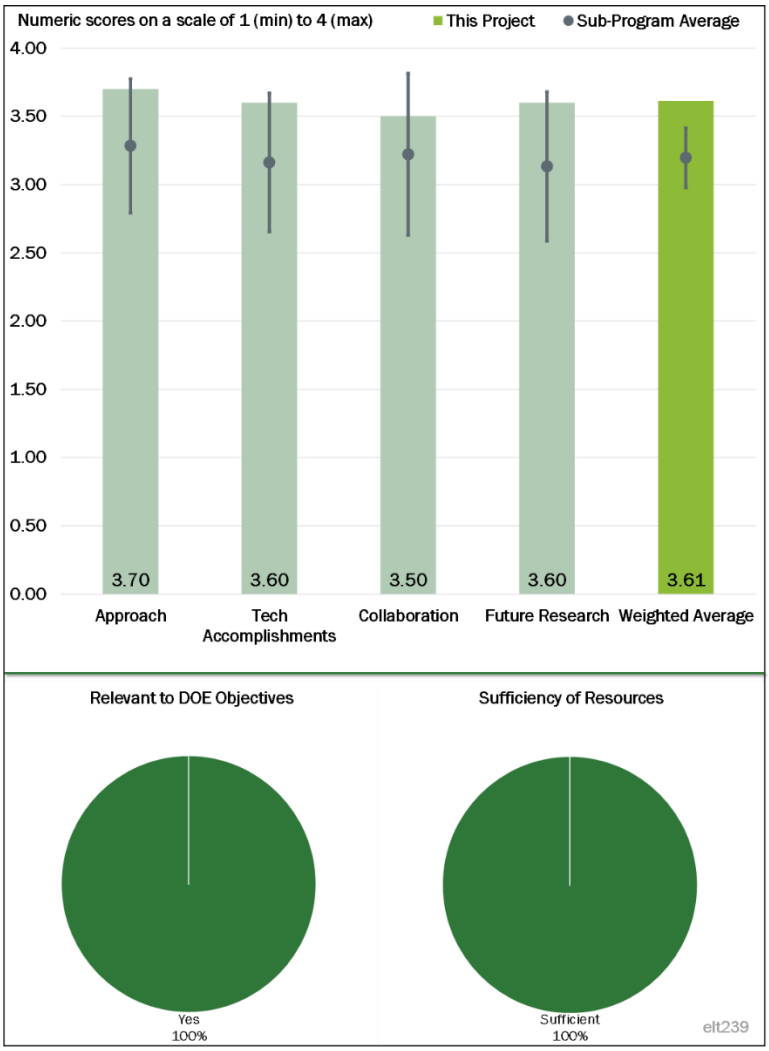

Figure 4-42 – Presentation Number: elt239 Presentation Title: High-Power Inductive Charging System Development and Integration for Mobility Principal Investigator: Omer Onar (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer stated this is a good use of both FEA modeling and validation testing. Sound approach to design power conversion stages in an integrated approach to provide both complexity and compactness, and then test separately before integration.

Reviewer 4:
The reviewer said the design of system power conversation stage uses an integrated approach comprising modeling and actual testing. The work uses actual vehicle battery and grid voltage and power level, making it easy for future deployment.

Reviewer 5:
The reviewer stated that the design and simulation followed by progressive scaling of technology onto consumer vehicles appears to be an effective approach to evaluation of technology readiness and commercial viability.

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

Reviewer 1:
The reviewer said the project appeared to show significant improvements over existing baseline designs, as well as demonstrate a working proof of concept for the initial design. The measured DC-DC efficiency shows a sensible check of the analytical efficiency prediction.

Reviewer 2:
The reviewer noted that this the first budget period, and the team has accomplished a lot, from modeling and analyzing 3-phase inverter variability duty cycles, to compared 3-phase inverter DC link ripple currents, and to design and prototype of a 3-phase high frequency inverter (which the reviewer presumes is at 300 kHz), and more importantly, designed and prototyped a 3-phase 2-layer polyphase coupler with 95.6% efficiency. This is amazing.

Reviewer 3:
The reviewer stated that in the first budget period the project team is targeting the complete design of the proposed system for 100 kW power transfer to the vehicle side, including all of the power conversion stages and coupling. The PI showed results for specific power analysis, 3-phase inverter, and a simulation model. Results indicate that the project is well underway to meet the performance indicators for this budget period.

Reviewer 4:
The reviewer noted that the project team appears to be methodically moving through their planned milestones, focusing on analysis, modeling and simulation, and design. For the most part, validated power was close to designed power, though there was much more variation in power density (some were close, some not quite so close). In particular, ORNL seems confident that it can control the charging system as needed to meet technical goals. In addition, it has completed bench-scale testing demonstrating 95% overall efficiency, another key parameter necessary that indicates a strong chance of meeting required charging levels.

Reviewer 5:
This reviewer said that substantial accomplishments have been achieved in the first budget period, including technology benchmarking and evaluation; selection of a system level approach and modular grid interface architecture; choice of a polyphase WPT system for high power density; and modeling and analyzing the 3-phase inverter variable duty-cycle control showing significant reductions in DC link ripple current and capacitance requirement. In addition, a 3-phase high frequency inverter was designed and prototyped that exceeds current DOE 2020 targets for power density, and a closed loop 3-phase power-factor correction (PFC) was developed with a step-down regulator.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that cooperation with EV OEMs will help understand the challenges facing the implementation of this technology and integration with battery requirements. Opportunities are shown for evaluating the technology at both 100 kW and 300 kW levels. The project collaboration appears well defined among partners.

Reviewer 2:
The reviewer said the research lab has teamed up with a commercial passenger vehicle manufacturer, a charging system developer, and an integrator. These appear to be appropriate and engaged partners.

Reviewer 3:
The reviewer said the project team has appeared to bring along the necessary parties for this particular technology—an EVSE manufacturer and vehicle manufacturers/integrators. Each team member has clear-cut roles based upon their expertise.

Reviewer 4:
This reviewer stated that the project collaborators are leaders in the field and their roles are clearly defined. Each collaborator has a specific contribution to the success of the program as a whole.

Reviewer 5:
The reviewer stated that it appears most of the work is done by the ORNL team in budget period 1. The project does clearly define each members' role.

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 project team has clearly laid out its planned future research under this project. Upon questioning, the principal investigator also indicated what might be needed after this project, such as greater charge rates and also impacts upon electric vehicles.

Reviewer 2:
The reviewer remarked that the proposed future work seems like a good progression of showing technology readiness.

Reviewer 3:
The reviewer noted that the proposed future research is to scale the design polyphase couplers and the inverter/rectifier to 300 kW target power, and the inverter with backward compatibility to 100 kW. This proposal is sound and natural.

Reviewer 4:
The reviewer stated that the future work seems appropriate given the accomplishments to date.

Reviewer 5:
This reviewer said the proposed future research focuses on key challenges, but little detailed specifics are provided for the future tasks.

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

Reviewer 1:
The reviewer said this project aligns with the DOE charging roadmap

Reviewer 2:
This reviewer stated that fast wireless charging is extremely important for vehicle electrification. This work directly and solidly addressed the overall DOE goal on reducing the barriers in vehicle electrification, wireless charging, and vehicle to grid integrations.

Reviewer 3:
The reviewer said yes—the project increases benefits and lowers barriers to vehicle electrification.

Reviewer 4:
The reviewer remarked that this project is focused upon one of the building blocks necessary to provide light-duty EV users with a gasoline station-like level of experience (10 minutes to 50% state-of-charge). This type of technological progress will be necessary to encourage greater penetration of electric vehicles.

Reviewer 5:
This reviewer stated that XFC is a key selling point of user convenience needed for widespread adoption of electric cars. It reduces the barriers to vehicle electrification, wireless charging, and vehicle-to-grid (V2G) integration and addresses range anxiety. It makes it more competitive with the fast refueling of internal combustion vehicles.

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

Reviewer 1:
The reviewer said the funding appears appropriate to the work which will be performed

Reviewer 2:
This reviewer said that for the current scope of the project, the funding appears sufficient, and shows an impressive level of cost-share from the partners (more than 55%).

Reviewer 3:
The reviewer noted that resources for this project are extremely large at $5 million for the development of a charger. However, given the complexity of the task, the new technologies being implemented, the importance of having safe and effective fast charging, and the fact that more than half the funding is cost share, it is not excessive.

Reviewer 4:
The reviewer stated that the funding looks like sufficient, but is not sure how the cost share of $3 million is planned.

Reviewer 5:
This reviewer said that the funding seems appropriate for the staff and prototype work. Any larger demonstrations would require additional funds.

Presentation Number: elt240
Presentation Title: Wireless Extreme Fast Charging for Electric Trucks (WXFC-Trucks)
Principal Investigator: Mike Masquelier (Wireless Advanced Vehicle Electrification)

Presenter
Mike Masquelier, Wireless Advanced Vehicle Electrification

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 and well-planned.

Reviewer 1:
This reviewer said the approach seems good for working with the project collaborators in establishing a 500 kW charging system for heavy-duty vehicles.

Reviewer 2:
This reviewer said the project follows the approach of design and simulate, prototype, industrialize, then field operation and evaluation. The reviewer appreciated the practicality of the project and the approach which includes the field operations.

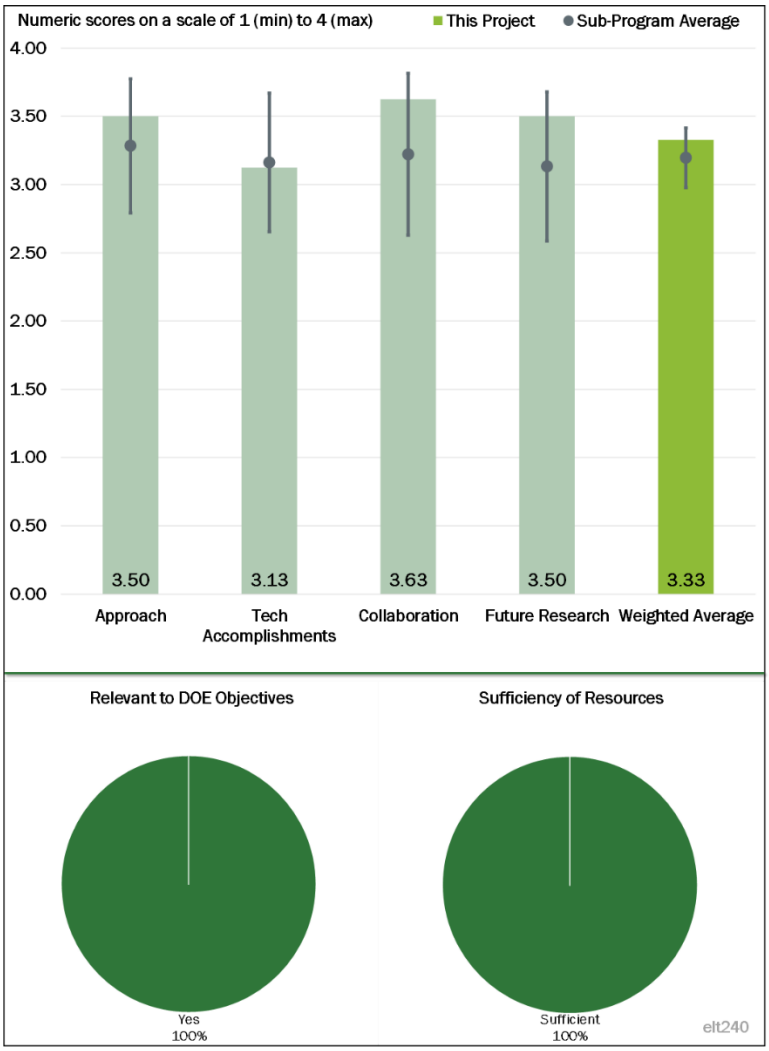

Figure 4-43 – Presentation Number: elt240 Presentation Title: Wireless Extreme Fast Charging for Electric Trucks (WXFC-Trucks) Principal Investigator: Mike Masquelier (Wireless Advanced Vehicle Electrification)

Reviewer 3:
This reviewer noted the project covers all facets of fast charging from the development of the on-board and off-board electronics for the charger to the deployment of the fast charger in a closed-loop shipping route for an actual truck at the Port of Los Angeles. The approach addresses both the technical aspects of the charger design and the practical aspects of its deployment.

Reviewer 4:
The reviewer stated that this is an important deployment project where there will be ground work formed for others to follow. Though this project had limited work completed due to its recent kick-off, the presenter noted a number of key barriers and clearly stated the approach to the getting the project into the demonstration phases. The project still needs to identify and address the International Commission on Non-Ionizing Radiation Protection (ICNIRP) or questions of other possible stray fields for WPT at these levels and airgaps.

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

Reviewer 1:
The reviewer said that progress on this project appears to be on track. Duty-cycle analysis is used to define requirements for implementation.

Reviewer 2:
The reviewer observed that the presenter showed the progress with the design and simulation, and the integration progress, as well as the 500 kW system design process. It appears that good progress had been made since August, however the Overview Slide noted that percent complete was just 10%.

Reviewer 3:
This reviewer said the project has good progress in selection of components and partners, the Primary team has previous work in this space and with the infrastructure part that is required early on in this type of project. Given its recent kick off, it is hard to give this a higher mark at this time. Reviewing during the second phase of the project will be more telling of their program and technical accomplishments.

Reviewer 4:
The reviewer observed that after the first year of the 3+ year program, only 10% of the full effort is complete. Nevertheless, the project has already selected the major power components; completed the thermal analysis for the power semiconductor devices and transformers to determine the system mechanical layout and charger cooling approach; developed the packaging; created a low voltage prototype to validate the control strategy; and started the transformer design. Furthermore, the site has been chosen for the deployment and the wireless pad designed. More work needs to be done on the battery selection and thermal management of the battery during fast charging.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said the project lead seems to have a good handle on what it takes to execute these projects and the types of partners needed to meet the targets. This reviewer had full confidence in the partners selected and the team's ability to execute on the project targets.

Reviewer 2:
This reviewer highlighted excellent collaboration with the Port of Los Angeles, the Los Angeles Department of Water and Power, Cummins Engine, and Transportation Services to secure the deployment vehicle and the deployment loop site. The reviewer also noted close collaboration with Schneider Electric and Utah State for the development of the charger. Team is well integrated and the roles are clear.

Reviewer 3:
The reviewer said this project has the right partners in the right areas to make this a successful project; the team just needs to execute.

Reviewer 4:
This reviewer noted that the partnership with local and private institutions appear good, but there appear to be concerns regarding the site selection for the charging system.

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 noted that the proposed future research is well-defined and addresses the key barriers and challenges.

Reviewer 2:
The reviewer said the future plans appear appropriate for the completion of the project objectives and address the challenges and barriers.

Reviewer 3:
This reviewer said the future work is well laid out and appropriate, given the activities completed thus far.

Reviewer 4:
The reviewer remarked that if successful in the future work, this will pave the way to new applications of electrification in this space. Good execution of this future work is critical

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

Reviewer 1:
The reviewer said this project is aligned to the Grid Integration Technical Team (GITT) roadmap for fast wireless charging systems.

Reviewer 2:
This reviewer said yes, because this project focuses on lower barriers for vehicle electrification.

Reviewer 3:
The reviewer stated that this is a critical component of medium-duty and heavy-duty truck electrification. This project is in direct alignment with VTO goals

Reviewer 4:
The reviewer said this is the first project that goes from charger design to site deployment, thereby demonstrating the practical reality of this technology leading to its adoption.

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

Reviewer 1:
The reviewer said the funding appears appropriate given the goals and objectives of the project.

Reviewer 2:
This reviewer said that given the level of funds for Year 1 and the percent complete of 10%, the funds for the first budget period seem high, however for the overall project they seem appropriate.

Reviewer 3:
This reviewer noted that with good cost share and support from the right partners, there is adequate funding for deployment.

Reviewer 4:
The reviewer stated that the resources are appropriate for a program of this size.

Presentation Number: elt241
Presentation Title: High-Efficiency, Medium-Voltage-Input, Solid-State-Transformer-Based 400-kW/1000-V/400-A Extreme Fast Charger for Electric Vehicles
Principal Investigator: Charles Zhu (Delta Electronics)

Presenter
Charles Zhu, Delta Electronics

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 and well-planned.

Reviewer 1:
This reviewer noted that a modularized, scalable, expandable, low cost XFC has been proposed that will increase efficiency by 3% while decreasing the footprint by 50% over the conventional solution. The approach to get there is well defined with key milestones. The charger will be a medium voltage, AC solid state transformer-based technology operated at high frequency with a cascaded multilevel soft-switching converter topology to reduce the number of power cells. Such a system is possible using SiC MOSFETs for low loss at medium voltage.

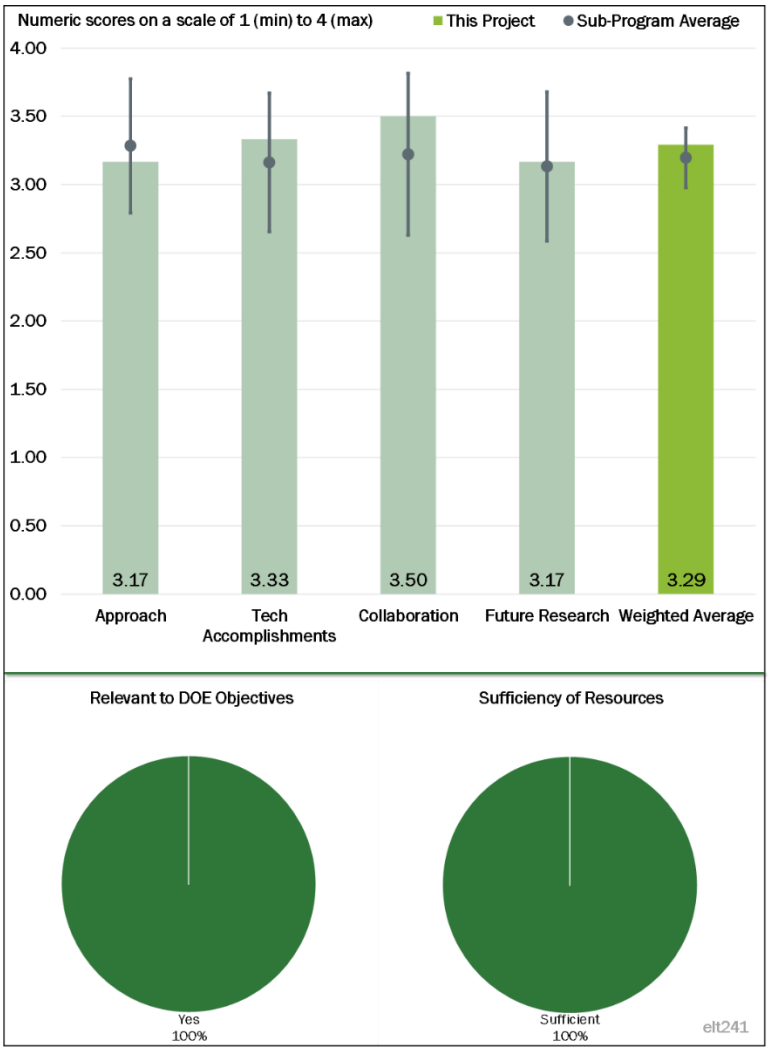

Figure 4-44 – Presentation Number: elt241 Presentation Title: High-Efficiency, Medium-Voltage-Input, Solid-State-Transformer-Based 400-kW/1000-V/400-A Extreme Fast Charger for Electric Vehicles Principal Investigator: Charles Zhu (Delta Electronics)

Reviewer 2:
The reviewer stated the project has a good approach and well laid out plan, the only question is regarding medium voltage selection and flexibility of technology. This was not discussed as a barrier but should be understood moving forward.

Reviewer 3:
The reviewer said the approach has been laid out as a series of technology efforts, with little detail or discussion concerning overall project flow/schedule (at least beyond the first year). The approach presented appeared logical, but it simply lacked a sufficient level of information.

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

Reviewer 1:
This reviewer stated that in just a few months since the start of the program, significant progress has been made. This includes designing the system structure and specification; designing the AC/DC stage; choosing the power cell topology; designing the medium voltage transformer; and analyzing the waveforms and efficiency of a prototype power cell. The charger module topology and packaging have also been designed and tested.

Reviewer 2:
The reviewer noted this project only started in December 2018. The results so far appear to indicate exceeding DOE objectives, so the project team increased the specification for the charger from 400 kW to 500 kW. The efficiency measurements also seem to have exceeded project goals so far.

Reviewer 3:
This reviewer stated that the execution of the approach is solid so far, though the discussion around getting medium voltage into the lab space was interesting. This reviewer is not familiar with working in this area and scaling tests to lower voltage, but that seems to be something that would not be adequate for proof of concept at this level.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted the team appears to include most of the partners critical to success—a vehicle manufacturer, two utilities, and a university. In addition, the team includes a state energy office and a local jurisdiction to assist with the (field) on-road validation efforts and issues. DTE Energy has a test cell for use by the project, while the State Energy Office is providing guidance on policies. NextEnergy will provide the test site, and is providing advice along the way based upon their experience with EV programs. The team has monthly coordination meetings.

Reviewer 2:
This reviewer commented that the project has a good group of partners providing support in the right areas to ensure that DELTA can focus on the XFC technology portion. Good coordination was observed by this reviewer.

Reviewer 3:
This reviewer stated that excellent partners have been chosen. However, the exact breakdown of tasks and responsibilities among the partners is 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 the proposed future research will allow for advancements to meet the barriers. It would be good for an interim report to be available to research groups in the power distribution and charging space.

Reviewer 2:
The reviewer noted that the project team has laid out the basic elements of future research needs, but has not provided much detail. The steps appear to make sense, but it would be good to have some details as to how each element will be accomplished.

Reviewer 3:
This reviewer noted that future work will address key barriers and challenges and expands on the current efforts, but details of the tasks and approaches are not provided.

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

Reviewer 1:
The reviewer noted this project is focused on successful demonstration of a 10-minute charge for 150 miles for a light-duty EV, all at medium voltage (more common). This is the sort of charging level performance that is seen by many as necessary to ultimately enable large-scale market penetrations for EVs. In addition, the system as envisioned is more flexible (to allow for integration of renewable energy and storage) and efficient.

Reviewer 2:
This reviewer said that fast charging is critical to widespread acceptance of EVs for user convenience and to address range anxiety.

Reviewer 3:
The reviewer said this is extremely relevant work leading to advancement in charging infrastructure and enabling medium- and heavy-duty electrification, as well as reducing need for research in some other forms of charging. The reviewer pointed out that we will still need to understand the demand charging impacts of this technology versus others.

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

Reviewer 1:
This reviewer stated that the resources appear sufficient at this time.

Reviewer 2:
The reviewer said the resources should be sufficient to allow the project to progress, as long as there are no missteps in the project timeline. If or when this transfers to increased power levels, additional development is required, then the resources may be tight. In that case—additional funding would be warranted given the importance of this work.

Reviewer 3:
This reviewer said the resources are very large for the design of a charger, but with the large scope of the effort and the 50% cost share, the resources are in line with the proposed work.

Acronyms and Abbreviations

°C	Degrees Celsius
AC	Alternating current
ADMM	Alternating direction method of multipliers
AMR	Annual Merit Review
ANL	Argonne National Laboratory
ANSI	American National Standards Institute
ARPA-E	Advanced Research Projects Agency – Energy
ATF	Automatic transmission fluid
AV	Autonomous vehicle
BEV	Battery electric vehicle
BTMS	Behind-the-meter storage
CAISO	California Independent System Operator
CFD	Computational fluid dynamics
CNO	Cyber network operations
CNT	Carbon nanotube
CO_2	Carbon dioxide
C-SAM	C-mode scanning acoustic microscope
Cu-Al	Copper-aluminum
Cu-Sn	Copper-tin
CVE	Common vulnerabilities and exposures
DBC	Database Container
DBC	Direct-bond copper
DC	Direct current
DCFC	Direct current fast charging
DER	Distributed energy resources
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy

DOT	U.S. Department of Transportation
DWPT	Dynamic wireless power transfer
Dy	Dysprosium
ECV	Electric and commercial vehicle
EDV	Electric drive vehicle
ELT	Electrification Technologies
EM	Electromagnetic
EPRI	Electric Power Research Institute
ES-C2M2	Electricity Subsector Cybersecurity Capability Maturing Model
ESR	Equivalence series resistance
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
FCA	Fiat Chrysler Automobiles
FE	Fuel economy
FEA	Finite element analysis
FY	Fiscal year
GaN	Gallium nitride
GBDP	Grain-boundary diffusion process
GITT	Grid Integration Tech Team
GW	Gigawatt
HCE	High consequence events
HEV	Hybrid electric vehicle
HIL	Hardware-in-the-loop
HPC	High performance computing
HRE	Heavy rare earth
IC	Internal combustion
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IGBT	Insulated-gate bipolar transistor

IIT	Illinois Institute of Technology
IMS	Insulated metal substrate
INL	Idaho National Laboratory
IPM	Interior permanent magnet
kHz	Kilohertz
L2	Level 2
LD	Light duty
MOSFET	Metal oxide semiconductor field-effect transistor
MTBF	Mean time between failures
NDA	Non-disclosure agreement
NMFTA	National Motor Freight Traffic Association
NREL	National Renewable Energy Laboratory
NTRC	National Transportation Research Center
OEM	Original equipment manufacturer
ORNL	Oak Ridge National Laboratory
PEV	Plug-in electric vehicle
PFC	Power factor correction
PHEV	Plug-in hybrid electric vehicle
PM	Permanent magnet
PNNL	Pacific Northwest National Laboratory
PTO	Power take-off
PWM	Pulse-width modulation
ROI	Return on investment
SAE	Society of Automotive Engineers
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
SCR	Selective catalytic reduction
Si	Silicon

SiC	Silicon carbide
SMC	Soft magnetic composites
SNL	Sandia National Laboratories
SPIN	Smart power integrated node
STRIDE	Spoofing, Tampering, Repudiation, Information disclosure, Denial of service, and Elevation of privileges
SwRI	Southwest Research Institute
SWTP	Static wireless power transfer
TCO	Total cost of ownership
TLPS	Transient liquid phase sintering
TPG	Thermal pyrolytic graphite
TTSI	Total Transportation Services, Inc.
V	Volt
V2B	Vehicle to bus
V2G	Vehicle to grid
VGI	Vehicle-grid integration
VMT	Vehicle miles traveled
VTO	Vehicle Technologies Office
WECC	Western Electricity Coordinating Council
WPT	Wireless power transfer
xEV	Reference to an electric vehicle, including battery electric vehicle (BEV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), etc.
XFC	Extreme fast charging
ZANZEFF	Zero-Emission and Near-Zero Emission Freight Facilities