4. Electrification Technologies

To strengthen national security, enable future economic growth, support energy dominance, and increase transportation energy affordability for Americans, the Vehicle Technologies Office (VTO) funds early-stage, high-risk research. The 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 and works with partners across industry and academia 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 connected and automated 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 U.S. Department of Energy (DOE) research on the most critical research and development (R&D) barriers, and accelerate progress. VTO focuses on research that industry either 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.

The Electrification R&D effort focuses on early-stage research to understand the potential impacts of electric vehicle (EV) charging on the nation's electric grid. This research informs the development of communication and cybersecurity protocols; enables industry to enhance the interoperability between charging equipment, the on-board vehicle charger, and charging networks; and fosters technology innovations to improve EV refueling through extreme fast charging (including high-power static and dynamic wireless charging). A focus on extreme fast charging (XFC) research will expand understanding of the charging infrastructure and electricity grid challenges to enabling a 15-minute or less battery charge. Current direct current fast-charge equipment operates at 50-120 kW. The goal for XFC research is to enable industry to develop and deploy 350+ kW power capability that enables EVs to charge in 15 minutes or less.

Electric Drive Research focuses on early stage research of extreme high-power density motor and power electronics that have the potential to enable radical new vehicle architectures by dramatic volume/space reductions and increased durability and reliability. This research emphasizes a ten-fold reduction in the volume of electric traction drive systems using high-density integration technologies, leveraging high-performance computing (HPC) for modeling and optimization, and utilizing new materials for high-density electric motors. Integration of electric traction drive systems based on power electronics and electric motor innovations is also a priority.

Subprogram Feedback

DOE received feedback on the overall technical subprogram areas presented during the 2018 Annual Merit Review (AMR). Each subprogram technical session was introduced with a presentation that provided an overview of subprogram goals and recent progress, followed by a series of detailed topic area project presentations.

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

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

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

Question 3: Were important issues and challenges identified?

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

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

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

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

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

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

Question 10: Has the program area engaged appropriate partners?

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

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

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

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

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

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

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

Presentation Number: bat918
Presentation Title: Battery and Electrification R&D Overview
Principal Investigator: Steve Boyd (U.S. Department of Energy)

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

Reviewer 1:
Yes, the program was covered to meet the needs of this reviewer. The material gave a very good overview of the DOE program and goals, and addressed the issues.

Reviewer 2:
The reviewer stated yes, and commented that the speaker did an excellent job of covering all facets of the battery and electrification research and development (R&D) efforts. Key challenges in each of the main areas of technology and how they were being addressed by ongoing research was discussed. This reviewer reported that the following were covered: lithium (Li)-ion and non-lithium battery cell development, including new low cobalt (Co) cathode and intermetallic alloy anode work; electric drive developments at higher voltages and lower costs; and grid issues, including fast charging and cybersecurity. A strong case was made for the need to reduce battery cost and charging time, along with the need to reduce cost and increase efficiency of the traction drive system to ensure large market penetration of electric drive vehicles (EDVs). This reviewer commented that concurrent grid infrastructure needs to support widespread acceptance of electric vehicles (EVs) was also addressed. As far as specific technologies are concerned, the presenter did a particularly good job of covering the wide array of outstanding work in the area of power electronics and motors for vehicle electrification.

Reviewer 3:
The reviewer responded positively and explained that battery life must be properly predicted for projects to be funded in the extreme fast charge Li-ion cell area. This reviewer inquired whether it is possible to develop a degradation model of various battery components so that a predictive model is developed, gets shared with stakeholders, and is tested to validate the developed model.

Reviewer 4:
This reviewer indicated yes and suggested the following strategy adjustments: cost of electric vehicle batteries to less than $100/kilowatt-hour (kWh) and $6/kilowatt (kW) for a 100 kW peak Electric Drive System (EDS); breakout targets by technology areas (e.g., motor, inverter, battery package, controls, and thermal systems); and breakout targets for hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), performance EV, and passenger EV.

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

Reviewer 1:
The reviewer responded positively and asserted that there is an excellent balance. The presentation addressed the very near-term 2020 to the longer-term 2030 goals, and provided future roadmap indicators for the technologies being reviewed.

Reviewer 2:
This reviewer stated yes. There is an appropriate balance with all three areas well covered, including nearer-term Li-ion battery development and electric drive research focused on cost reduction; mid-term advanced cell battery, high-voltage electric drive, two-phase cooling, multiphysics integration, and grid integration work; and long-term research on extreme fast charging, new materials development, and cybersecurity,

Reviewer 3:
The reviewer commented that there is a need to make some adjustments. Regarding $6/kW for a 100 kW peak, the reviewer provided the following link to show that HEV sales are slowing (down 19.0%) and strong electric

plugged xEVs are increasing (up 46.0%). The reviewer cited an Argonne National Laboratory study of light-duty EDV sales update (http://www.anl.gov/energy-systems/project/light-duty-electric-drive-vehicles-monthly-sales-updates). With this in mind, the reviewer stated that future targets need to address the higher power requirements for battery, power electronics, and electric drive. Further, this reviewer noted that 100kW is low as a reference point for the future.

Reviewer 4:

This reviewer indicated yes. For wide bandgap (WBG) devices, the reviewer commented that it is necessary to cover voltage range from 48 volt (V) to 1,700V. The reviewer suggested that development of cost and performance optimized silicon carbide (SiC) power package could be one of the long-term (5 years) research goals.

SiC and gallium nitride (GaN) devices are far smaller than Si devices. Therefore, to keep inverter foot-print optimized and smaller, the reviewer explained that it is necessary to have an Application-Specific Integrated Circuit (ASIC) for gate driver circuit that should consist primarily of gate driver circuitry, including isolated power supplies and their watchdogs. The reviewer suggested this could be a mid-term goal and could raise the possibility of wide acceptance of SiC and GaN power converter technology for EVs, HEVs, PHEVs, etc.

Question 3: Were important issues and challenges identified?

Reviewer 1:

This reviewer stated yes, and noted that critical issues included cost reduction, power density increases, increased charging speed, grid integration, cybersecurity, and methods to address range anxiety (e.g., longer battery life and improved infrastructure).

Reviewer 2:

In this overview presentation, the reviewer observed several areas were addressed that impact the future of vehicle electrification. Each area had technical issues and challenges that needed to be addressed, which were done to this reviewer's satisfaction.

Reviewer 3:

The reviewer stated yes, except for how manufacturing will be advanced to support project activities dedicated to achieve 2025 power density and cost targets for electric drive technologies.

Reviewer 4:

This reviewer identified key emerging challenges on the horizon. Firstly, marriage of autonomous with EV means that power management of the low voltage power bus has become safety critical and a challenge in the increased required power for all of the electric actuation and sensing, which could be more than 5kW. Secondly, the reviewer noted that electrical, battery, and component thermal management aspects for extreme fast charging are certainly needed as a future challenge. Finally, this reviewer highlighted the influence of fast charge on graphite life, nickel manganese cobalt oxide (NMCxxx), Si, or silicon oxides (SiO_x).

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

Reviewer 1:

The reviewer responded positively and noted that plans to address critical issues and challenges included cooling and multiphysics integration techniques to permit cost reduction and electric drive power density increases. New charger designs and battery cell materials were also proposed for increased charging speed, along with programs to improve grid integration and infrastructure.

Reviewer 2:

This reviewer stated yes, the plans for addressing the issues and challenges associated with the different technologies were identified. The presentation also provided the funding scheduled to support that work. The

reviewer further highlighted that one major and key method identified involved forming collaborative teams that included the various labs and industry.

Reviewer 3:
The reviewer remarked that plans were somewhat identified for addressing issues and challenges, and suggested that plans may need minor or major changes as research progresses to achieve 2025 targets.

Reviewer 4:
This reviewer commented to continue U.S.-based WBG based component development—Tesla now has in its Model 3—and suggested this should be supplied and implemented by somehow leveraging overall domestic capability. The reviewer then referenced battery fast charge as related to electrochemistry and thermals. Regarding battery cost, the reviewer noted low cost chemistry (e.g., lithium manganese oxide [LMO]), and suggested to consider funding original equipment manufacturer (OEM) or supplier-based battery cell prototype equipment to speed learning in domestic locations.

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

Reviewer 1:
Progress from last year was somewhat benchmarked against 2016-2017, as indicated by this reviewer. The trend tended toward progress over a larger timeframe that highlighted steady growth based on technology developments.

Reviewer 2:
This reviewer remarked that progress was somewhat clearly benchmarked against the previous year. For example, the reviewer highlighted a very nice chart showing the reduction in battery cost per year, and suggested that adding a full chart of the major accomplishments in the previous year, the current year, and the planned upcoming year would be nice.

Reviewer 3:
The reviewer stated yes, from a budget perspective, but was unsure whether this could be extrapolated to a technology-based progress. The reviewer suggested it might be worthwhile to have a perspective similar to the Advanced Combustion Systems team, which shows progress in emissions, power, power density, and 0-60 miles per hour (MPH) vehicle performance over time.

Reviewer 4:
This reviewer reported that 2020 and 2025 targets are quite different.

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

Reviewer 1:
The key goal of the VTO office, as indicated by this reviewer, is to make electric drive vehicles competitive with fossil fuel powered vehicles in all aspects, particularly performance, cost, and overall life. The reviewer remarked that the projects and plans, as outlined, address the technical issues that need to be overcome to meet those goals.

Reviewer 2:
This reviewer stated yes, the projects in this technology area are all aimed at reducing cost, enhancing performance and efficiency, and improving the driving experience (e.g., increasing range, reliability, and security) to promote widespread EV acceptance and thereby minimize carbon emissions and fossil fuel use.

Reviewer 3:
The reviewer indicated that the projects in this technology area somewhat address the broad problems and barriers that VTO is trying to solve, and noted that projects should have a clear pathway for commercialization.

Reviewer 4:
This reviewer responded yes, generally, and recommended a continued focus to get performance up and cost down. One gap the reviewer identified is the marriage of autonomous with EV, which means that power management of the low voltage power bus has become safety critical and a challenge in the increased required power, Automotive Safety Integrity Level (ASIL) D safety, and power management for all of the electric actuation and sensing. The reviewer added that the required could be even more than 5kW.

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

Reviewer 1:
The reviewer remarked yes; focus is maintained in the most fruitful areas for research. This reviewer observed excellent management at all levels from Steven Boyd, the Program Manager, who is an exceptional leader, to his experienced and expert team, especially Susan Rogers, who leads the electric drive efforts.

Reviewer 2:
This reviewer agreed that the program area appears to be focused, well-managed, and effective in addressing VTO needs. The reviewer reported that the presentation material outlines the areas that will address current, near-term, and future goals. The material covered areas that are needed on the vehicle side as well as much of the infrastructure concerns.

Reviewer 3:
The reviewer responded positively and commented that, in electric machine R&D work, material properties should be modeled to predict how new material will perform for various mission profiles (tow-speed characteristics) required by EVs, HEVs, PHEVs, etc.

Reviewer 4:
This reviewer asserted that an initiative is needed to attract the new and emerging EV companies to participate and suggested that DOE at least make some focused visits to those new companies to collaborate.

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

Reviewer 1:
The reviewer expressed that the projects cover a wide range of topics, but are all complementary and focused toward electric vehicle improvement. Projects focused specifically on critical challenges include those related to design, packaging, thermal management, and reliability of innovative chargers and batteries for fast charging and for the grid infrastructure to support them. This reviewer explained that projects were well supported and had a nice balance of innovation and practicality that permitted significant and achievable progress in a reasonable time.

Reviewer 2:
One area that the reviewer identified was the need to have more visible support and/or input from the U.S. Department of Transportation (DOT). That involvement is undoubtedly there, but it was not clearly presented. The work with batteries was a focus of this reviewer, who indicated that the work in that area continues to push the envelope of understanding the issues and resolving them.

Reviewer 3:
This reviewer asserted that cost is key. Although there could be some more detailed trade-off on power density versus cost and manufacturability to meet cost, the reviewer commented that it will continue to lag in adoption without profitable electrification technology.

Reviewer 4:
This reviewer opined that there is too much focus on electric machine technology and little focus on inverter technology. The reviewer advised that attention to battery technology with a clear focus towards commercialization should be given due attention.

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

Reviewer 1:
The reviewer indicated that the projects are novel and represent innovative ways to approach solutions to the issues involved. Further, this reviewer observed a multi-prong collaborative task force with a single mission, using analytical and testing tools from several labs is being used, which is both novel and innovative.

Reviewer 2:
This reviewer stated yes and highlighted some of the more novel approaches: microporous silicon anodes; Co-free cathodes; fundamental materials characterization of Li cells for extreme fast charging; use of multiphysics for device and package integration; two-phase cooling; and high voltage, WBG power converters.

Reviewer 3:
The reviewer agreed that these projects represent novel and/or innovative ways to approach these barriers. Alternative and variant cooling methods including phase-change cooling related projects should be funded to realize a power-dense air-cooled power converter, which this reviewer asserted will support adoption of the WBG technologies.

Reviewer 4:
Regarding extreme fast charging, this reviewer explained that, perhaps, the critical enabler of 800V max batteries is not so novel or innovative. Of course, the reviewer continued, this then drives needed work in high voltage (HV) power electronics and electric drives.

Question 10: Has the program area engaged appropriate partners?

Reviewer 1:
This reviewer stated yes; each of the projects has identified leaders in the field for collaboration. The level of industrial, academic, and government laboratory interactions in this program is impressive and the partners chosen are recognized experts.

Reviewer 2:
The reviewer responded positively and asserted that vehicle OEMs, battery manufacturers, national laboratories, and parts manufacturers for the battery manufacturers are all involved.

Reviewer 3:
This reviewer opined that industry, university, and DOE lab partnership should be encouraged to solve problems perceived as difficult and/or impossible.

Reviewer 4:
The reviewer commented that, generally, getting major OEMs is key. However, the reviewer indicated that there could be some sort of initiative needed to attract new and emerging EV companies to participate. This reviewer suggested that DOE at least make some focused visits to those new companies to collaborate.

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

Reviewer 1:
The reviewer responded positively and observed regular, arranged meetings with updates that are provided. This reviewer further commented on dynamic direction and support that is delivered based on progress.

Reviewer 2:
This reviewer stated yes and suggested that industry, university, and DOE national laboratory partnerships should be further encouraged to solve problems perceived as difficult and/or impossible.

Reviewer 3:
Generally, the reviewer reported significant evidence of strong collaboration with industry and academia, as well as other government laboratories, though it depends on the project. Each partner is supplying a key appropriate aspect of each project, whether new materials, design expertise, modeling expertise, components for test, or facilities.

Reviewer 4:
The reviewer noted a basic model focus on having OEMs and suppliers build functional prototypes. This reviewer also observed labs and universities on materials, basic research, and studies.

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

Reviewer 1:
The reviewer remarked that gaps have been identified, but are a risk level that allows them to exist until the key items are addressed. This reviewer added that the focus has to be on areas that will drive success rather than areas that may have some limited value.

Reviewer 2:
Regarding the design for "Giga-Watt-Hr" (GWh) production of battery cells and packs, this reviewer commented that electrochemistry is important, but will need the balance with manufacturing at large scale to be a factor. Although reducing Co and other materials saves money, so does a more efficient manufacturing technique.

Reviewer 3:
This reviewer indicated that it seems like Li-ion batteries are tracking quite well with the desired trends for cost reduction, as this is happening year after year. In the category of beyond Li-ion projects, there should be some focus to improve Li-Ion technology too; this is needed for large scale adoption of EVs. The reviewer opined that car drivers still have battery reliability in mind when they hit car dealers to buy an EV.

Reviewer 4:
The reviewer recommended other areas to investigate, including the following: three-dimensional (3-D) packaging, including additive manufacturing; electro-thermal-mechanical-reliability co-design; high voltage thin film insulators; and new WBG semiconductors (e.g., gallium oxide [GaO], diamond).

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

Reviewer 1:
The reviewer asserted that key topics to make this technology reach stated goals are being addressed.

Reviewer 2:
This reviewer commented that future targets need to address the higher power requirements for battery, power electronics, and electric drive, and further highlighted that 100 kW is low as a future reference point.

Reviewer 3:
According to this reviewer, some attention should be given to enabling technologies for inverters, such as packaging material; thermal management materials, including advanced cooling technologies for inverters; inverter interconnects; motor; and connectors, etc.

Reviewer 4:
The reviewer referenced prior comments.

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

Reviewer 1:
This reviewer recommended ensuring state of charge (SOC) and state of health (SOH) algorithms during these events as related to extreme fast charging.

Reviewer 2:
The reviewer suggested other potential areas that may need funding to meet the overall goal of vehicle electrification.

Reviewer 3:
The reviewer commented that eliminating resistive contacts within an inverter and between motor and inverter should be given due consideration. The reviewer explained that, often, Electric Drive (ED) fails or life of ED reduces due to heating of various inter connects within ED system.

Reviewer 4:
This reviewer referenced prior comments.

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

Reviewer 1:
The involvement of the different national laboratories and OEMs has allowed for a multitude of counselors to be involved in evaluating and suggesting all viable approaches that this reviewer could envision.

Reviewer 2:
The program's current approach was described by this reviewer as well on track.

Reviewer 3:
This reviewer was unable to offer any quality ideas.

Reviewer 4:
The reviewer remarked that capturing requirements early should be encouraged for each project. Further, this reviewer suggested accomplishing this by identifying a specific application of underlying technology being developed through DOE-VTO funding. Often, R&D work goes somewhat satisfactorily; however, research faces the valley of death due to lack of adoption when research outcomes fall short in addressing application needs. The reviewer opined that this can be addressed by encouraging industry partnership with a commitment to demonstrating technology in an identified application.

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

Reviewer 1:
The reviewer commented that this presentation did exactly what was needed—it gave a very good overview of the programs involved, their tasks, goals, and accomplishments. This presentation was also effective as it highlighted some of the key issues that must be overcome.

Reviewer 2:
The reviewer stated none.

Reviewer 3:
Continuing focus on the most critical constraints to a widespread market penetration of electric vehicles (i.e., cost, range, and reliability) was recommended by this reviewer.

Reviewer 4:
This reviewer suggested that increased involvement of industry reviewers should be considered during selection of projects for DOE-VTO funding. If possible, university and DOE national laboratory projects should have industry advisors with application-oriented mindsets. Otherwise, continued this reviewer, DOE-VTO funded R&D work runs the risk of falling into the valley of death.

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
elt015	Part Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors 1	Iver Anderson (Ames Laboratory)	4-15	2.86	3.00	3.29	2.57	**2.95**
elt049	Advanced High-Performance Computing (HPC) Multiphysics Modeling of Motors and Materials	Jason Pries (ORNL)	4-21	3.17	3.33	3.08	3.17	**3.24**
elt054	Drivetrain Performance Improvements Techniques	Gui-Jia Su (ORNL)	4-25	3.20	3.30	3.00	3.00	**3.20**
elt071	Ultraconducting Copper	Tolga Aytug (ORNL)	4-29	3.08	3.17	2.92	2.75	**3.06**
elt074	Non-Rare Earth Electric Motors †	Tsarafidy Raminosoa (ORNL)	4-34	3.17	3.00	3.00	2.83	**3.02**
elt075	Electric Motor Thermal Management	Kevin Bennion (NREL)	4-37	3.36	3.29	3.21	3.07	**3.27**
elt077	Innovative Converters and Chargers †	Veda Galigekere (ORNL)	4-42	3.38	3.13	3.13	3.00	**3.17**
elt078	Power Electronics Thermal Management	Gilbert Moreno (NREL)	4-45	2.93	2.79	3.00	2.71	**2.84**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
elt079	Advanced Multiphysics Integration Technologies and Designs	Emre Gurpinar (ORNL)	4-50	3.00	3.13	3.13	3.25	**3.11**
elt080	Performance and Reliability of Bonded Interfaces for High-Temperature Packaging †	Paul Paret (NREL)	4-53	3.17	3.50	3.33	3.33	**3.38**
elt089	Motors Assessing the North American Supply Chain for Traction Drive Inverters, and Batteries for Class 3-8 Hybrid Electric and Plug-In Electric Commercial Vehicles	Chris Whaling (Synthesis Partners)	4-56	3.00	2.75	3.00	2.63	**2.83**
elt090	Soft Dual-Phase Non-Magnetic Laminates for Low-Cost-Reduced Rare-Earth Containing Electrical Machines	Francis Johnson (GE Global Research)	4-60	3.25	2.75	3.00	3.00	**2.94**
elt091	Cost-Effective 6.5% Silicon Steel Laminate for Electric Machines	Jun Cui (Iowa State U.)	4-62	3.13	3.25	3.13	2.88	**3.16**
elt092	Wound Field and Hybrid Synchronous Machines for Electric Vehicle Traction with Brushless Capacitive Rotor Field Excitation	Ian Brown (Illinois Institute of Technology)	4-66	2.88	3.13	3.13	3.00	**3.05**
elt093	High-Speed Hybrid Reluctance Motor with Anisotropic Materials	Edwin Chang (General Motors)	4-70	2.50	2.50	2.75	2.88	**2.58**
elt094	Development and Demonstration of Medium- and Heavy-Duty Plug-In Hybrid Work Trucks	John Petras (Odyne Systems)	4-73	3.00	3.00	3.20	2.80	**3.00**
elt095	Vehicle-to-Grid Electric School Bus Commercialization Project	Andy Moore (Blue Bird Corp.)	4-78	2.90	3.10	3.10	3.00	**3.04**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
elt115	Zero-Emission Drayage Truck Demonstration (ZECT I)	Phil Barroca (SCAQMD)	4-83	3.42	3.42	3.75	3.17	**3.43**
elt116	Zero-Emission Delivery Vehicle Deployment	Andrew DeCandis (Houston-Galveston Area Council)	4-88	2.80	2.80	2.90	3.10	**2.85**
elt158	Zero-Emission Cargo Transport II: San Pedro Bay Ports Hybrid & Fuel-Cell Electric Vehicle Project	Joseph Impullitti (SCAQMD)	4-93	3.00	3.10	2.90	2.80	**3.01**
elt187	Vehicle Comprehensive Assessment of On- and Off-Board-to-Grid Technology Performance and Impacts on Batteries and the Grid	Sunil Chhaya (EPRI)	4-98	3.20	3.30	3.60	3.30	**3.31**
elt188	Bi-Directional Wireless Power Flow for Medium-Duty Vehicle-to-Grid Connectivity	Steven Sokolsky (CALSTART)	4-102	3.70	3.40	3.40	3.30	**3.46**
elt189	Electric Truck with Range-Extending Engine (ETREE)	John Kresse (Cummins)	4-106	3.10	2.90	3.00	2.90	**2.96**
elt190	Medium-Duty Urban Range Extended Connected Powertrain (MURECP)	Alexander Freitag (Bosch)	4-110	2.88	3.13	3.00	3.13	**3.05**
elt191	Medium-Duty Vehicle Powertrain Electrification and Demonstration	Wiley McCoy (McLaren)	4-113	3.20	3.20	3.40	2.60	**3.15**
elt193	Grid Modernization Laboratory Consortium: Vehicle-to-Grid Integration Pathway (GM0062)	Rick Pratt (PNNL)	4-117	3.38	3.25	3.13	3.13	**3.25**
elt194	Grid Modernization Laboratory Consortium: Systems Research for Standards and Interoperability (GM0085)	Don Scoffield (INL)	4-120	3.38	3.25	3.25	3.25	**3.28**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
elt196	Grid Modernization Laboratory Consortium: Diagnostic Security Modules for Electric Vehicle-to-Building Integration (163)	Kenneth Rohde (INL)	4-123	3.60	3.60	3.50	3.60	**3.59**
Overall Average				**3.13**	**3.13**	**3.16**	**2.99**	**3.12**

† Denotes poster presentation.

Presentation Number: elt015
Presentation Title: Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors, Part 1
Principal Investigator: Iver Anderson (Ames Laboratory)

Presenter
Matt Kramer, Ames Laboratory

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

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

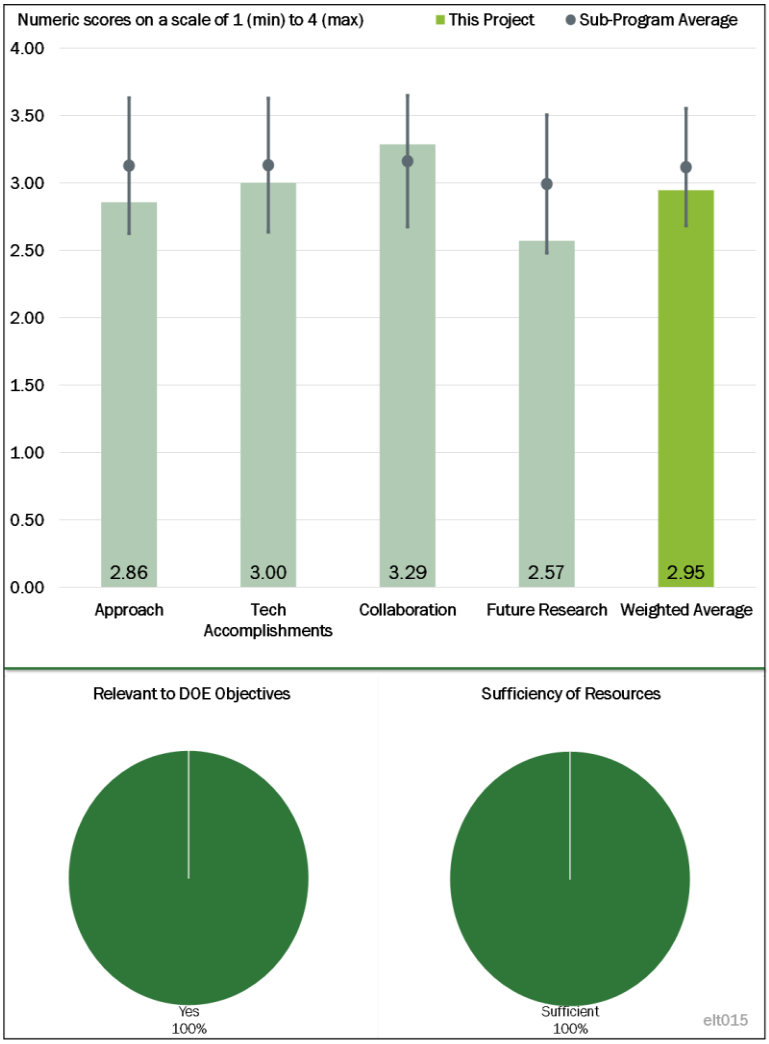

Figure 4-1 - Presentation Number: elt015 Presentation Title: Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors, Part 1 Principal Investigator: Iver Anderson (Ames Laboratory)

Reviewer 1:
The reviewer called this a highly integrated project with modeling and advanced characterization that is scheduled to end in September 2018. The objective is to design and synthesize a high-energy product aluminum-nickel-cobalt-(AlNiCo) permanent magnet (PM) competitive with rare earth (RE) PM (residual induction [Br] in excess of 0.8 tesla (T) and intrinsic coercive force (Hci) in excess of 2,500 Oersted [Oe]). The reviewer explained that the overall approach includes two different activities: near-term, non-RE magnets and long-term, non-RE magnets targeting 20 Megagauss Oe (MGOe) energy product. Specifically, the reviewer pointed out that the approach includes fabrication of well-controlled bulk magnet samples with enhanced grain alignment and energy product and with mechanical properties, all exceeding commercial AlNiCo magnets.

Reviewer 2:
The reviewer remarked that the program seeks to enhance the magnetic properties of AlNiCo magnet material to make it more competitive with RE-based magnets in terms of achieving similar performance. The targets for Hci and Br are laid out clearly and were defined with input from industry. The technical barriers are well known and the resources are well suited to address the problem. The reviewer asserted that the project team is taking an analysis-based approach along with experiments and testing at a scale that can be implemented in a final product. The reviewer thought that all of these steps make this approach well thought out and risk reduced.

Reviewer 3:
The reviewer indicated that the project lacks a clear understanding of primary traction motor applications needs and competing technologies (grain boundary diffused PM and heavy rare earth [HRE]-free PM).

Reviewer 4:
The reviewed stated that this effort of developing higher coercivity AlNiCo has been ongoing for a long time and it is not clear that there is a well-defined path of reaching coercivity/energy product levels that can ultimately enable competitive RE-free designs. The reviewer said that more quantification of motor performance enabled by the achieved AlNiCo properties so far (as well as targeted properties) should be provided.

Reviewer 5:
The reviewer commented that performance of non-rare-earth magnets drop with an increase in temperature. This could lead to significant variations from one electric machine to the next electric machine produced using non-rare-earth magnets. In general, for EV applications, the electric machine is characterized; however, the significant variation in magnetic properties of the non-rare-earth magnet cannot be adequately addressed by characterization.

Reviewer 6:
The reviewer expressed concern that the project does not consider how this work can translate into something competitive with today's strong PM machines desired by industry that are free of HRE materials.

Reviewer 7:
The reviewer asserted that the objectives for this project are not clearly defined. The Milestones slide shows as an objective the design of a high energy product AlNiCo PM competitive with RE PM (cost/MGOE/kilogram [kg]). But, the reviewer noted, the key deliverables and go/no-go decision point set a much easier target, which is to design an improved magnet (0.8T, 2,500 Oe) only exceeding conventional AlNiCo 8 or 9. The reviewer questioned whether a magnet with these properties could support a motor design that meets the DOE 2025 power density 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 discussed the technical accomplishments that included cluster expansion and Monte Carlo simulations guiding annealing and agreeing with microstructure analysis (theory and modeling), magnetic field anneal optimization of coercivity (synthesis of bulk magnetic samples), and achievement of full-size, complex-shaped magnets. Additionally, in terms of mechanical and thermal properties, the reviewer stated that sintered magnets show enhanced strength to improve assembly reliability and permit high motor speeds.

Reviewer 2:
The reviewer said that half of the goals have been achieved, Hci was shown to be improved to above the target based on actual material development and testing. Achieving the other goal of Br greater than .8 T is within reach as it is a matter of grain alignment and improving the magnetic alignment/annealing process. The reviewer commented that process development takes time, and considering the steps involved in this type of development, the program is going well from an execution standpoint.

Reviewer 3:
The reviewer noted that the principal investigator (PI) has carried out simulations and experimental work to accomplish project milestone

Reviewer 4:
The reviewer indicated that progress has been made and the materials work is well thought-out.

Reviewer 5:
The reviewer said that when considering the premise that the new magnet material only has to be better than conventional AlNiCo 8 or 9, good progress has been made. It would be useful if the PIs could show the new AlNiCo material in comparison to a very low-grade NdFeB magnet and include a cost comparison of these two magnets with similar magnetic properties. Although attempts have been made to reduce the amount of cobalt in the new magnets, the reviewer questioned if a magnet with significant amounts of cobalt content is the right path to low cost.

Reviewer 6:
The reviewer stated that the magnet has been significantly improved over the course of the program, but still falls short on performance for automotive traction applications.

Reviewer 7:
The reviewer remarked that there has been improvement in coercivity by about 25%, but this is still far away from reaching a level that can enable competitive motor designs

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer found active engagement and contributions by project partners including Oak Ridge National Laboratory (ORNL), Arnold Magnetics, and the University of Nebraska. Additionally, collaborators include Ford, UQM, GE, National Renewable Energy Laboratory (NREL), University of Wisconsin – Madison, Baldor, and Carpenter Powder Products.

Reviewer 2:
The reviewer pointed out that collaboration with team members seems to be going well, and there has been collaboration with Arnold and Carpenter on the processing and materials side. There has been collaboration with industry in defining targets and geometry for motor implementation.

Reviewer 3:
The reviewer said that the project has a highly collaborative and diverse team.

Reviewer 4:
The reviewer indicated that this project has many collaborators and partners, some of them from industry, which is very good. However, the crucial question is whether the collaboration with both GE and UQM, which this reviewer emphasized was started in 2012, will lead to any AlNiCo magnet motor designs that show any promise as a traction motor.

Reviewer 5:
The reviewer said that the lack of a real motor that meets an OEM requirements would have strengthened the argument that AlNiCo can meet the needs of an automotive application.

Reviewer 6:
The reviewer noted that there are a large number of collaborators and it is not clear the level of involvement of each of them.

Reviewer 7:
The reviewer reported that the project team consists of Ames Laboratory, NREL, ORNL, industries, and two universities. However, from project report and oral presentation, it is not clear what the roles and responsibilities of various team members and collaborators are.

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

Reviewer 1:
According to the reviewer, the PI has identified impactful tasks under the Future Research section of the project report.

Reviewer 2:
The reviewer noted that the remaining fiscal year (FY) 2018 tasks include developing focused theory and simulation, synthesizing test samples, and characterizing them. Suggested FY 2019 follow-on to this project (work scheduled to end in September 2018) would be to promote team interactions, develop additional focused theory and simulation, perform characterization, and synthesize additional test samples.

Reviewer 3:
The reviewer commented that future research seems focused on further gradual improvement of the new materials. It does not appear as if there are any major breakthroughs expected.

Reviewer 4:
The reviewer said that there is limited future work as the project ends by the fourth quarter of FY 2018. The follow-up motor work planned at ORNL is not formally outlined.

Reviewer 5:
The reviewer stated that there are proposed tasks for further improving coercivity, but it was not clear that there is a path for doubling the coercivity or achieving significantly higher coercivity than the achieved 2,500 Oe.

Reviewer 6:
The reviewer stated that in terms of what is needed to achieve the next goal of improving Br, there seems to be a well-defined plan and good understanding of what is needed. It was a little unclear to the reviewer in terms of what the plan was for demonstration in a final product.

Reviewer 7:
The reviewer was concerned that the project will not have anything usable by industry for EV traction motor applications.

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

Reviewer 1:
The reviewer remarked that in general, the development of new magnet materials is relevant to meet the DOE 2025 targets.

Reviewer 2:
The reviewer stated that development of RE-free PMs for electric drive motors directly supports DOE goals of improving vehicle fuel efficiency (electric drive versus internal combustion engine) and domestic energy security (reduced reliance on imported petroleum and RE metals).

Reviewer 3:
The reviewer said that if higher coercivity AlNiCo can be achieved, it can enable RE-free motor designs, which is consistent with DOE's vision

Reviewer 4:
The reviewer stated that the project was supportive of DOE objectives when it was initiated. However, it has fallen short of competitive technologies that will support DOE objectives while meeting OEM traction application requirements.

Reviewer 5:
The reviewer said yes, for cost because the development of the improved AlNiCo material could help address the Vehicle Technologies Office (VTO) targets in terms of cost; however, it depends on the relative demand and stability of cobalt elements versus RE elements. It is difficult to predict which elements will be costlier and more difficult to procure in the future; even so it represents a good hedge to any rise in RE element prices.

The reviewer said, no, for power density because the targets set for the AlNiCo magnetic properties make it relatively comparable to NdFeB- based motors in terms of power density today if used in an appropriate motor topology. Other improvements beyond the improved properties of AlNiCo will be needed to meet the new aggressive targets for power density for 2025.

Reviewer 6:
The reviewer pointed out that power-dense, low-cost, high-performance electric machines are required to meet 2025 cost and power density targets outlined by DOE VTO. This project somewhat addresses these objectives, except there is no clarity about adoption and large-scale commercialization.

Reviewer 7:
The reviewer stated that the project has the best of intentions, but market changes/realities need to be considered.

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 is sufficient.

Reviewer 2:
The reviewer believed that Ames has sufficient resources to complete the work on the magnet.

Reviewer 3:
The reviewer commented that resources are sufficient based on the proposed scope.

Reviewer 4:
The reviewer noted that the PI has sufficient resources and the PI's plan to interact with collaborators will further streamline and put in place resources needed in successful execution of this project

Reviewer 5:
The reviewer said that resources are sufficient. Highly qualified people are assigned to the project.

Reviewer 6:
The reviewer stated that the materials researchers at Ames and associated partners have excellent knowledge and experience for executing this type of research and development and seem positioned for completion of goals. Due to the change in DOE targets, a reassessment of the goals of this program and how it will address design requirements at the motor level may be needed. The resources for doing this also appear to be in place with Ford and other industry members.

Reviewer 7:

The reviewer remarked that this project received $1.4 million in FY 2017 and $700,000 in FY 2018 funding. The FY 2018 funding level has reduced the number of project team members, which has likely affected the potential technical achievements. The DOE Technology Commercialization Fund project was mentioned as a complimentary pathway for net-shape AlNiCo magnets commercialization with suppliers and OEMs.

Presentation Number: elt049
Presentation Title: Advanced High-Performance Computing (HPC) Multiphysics Modeling of Motors and Materials
Principal Investigator: Jason Pries (Oak Ridge National Laboratory)

Presenter
Jason Pries, Oak Ridge National Laboratory

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

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

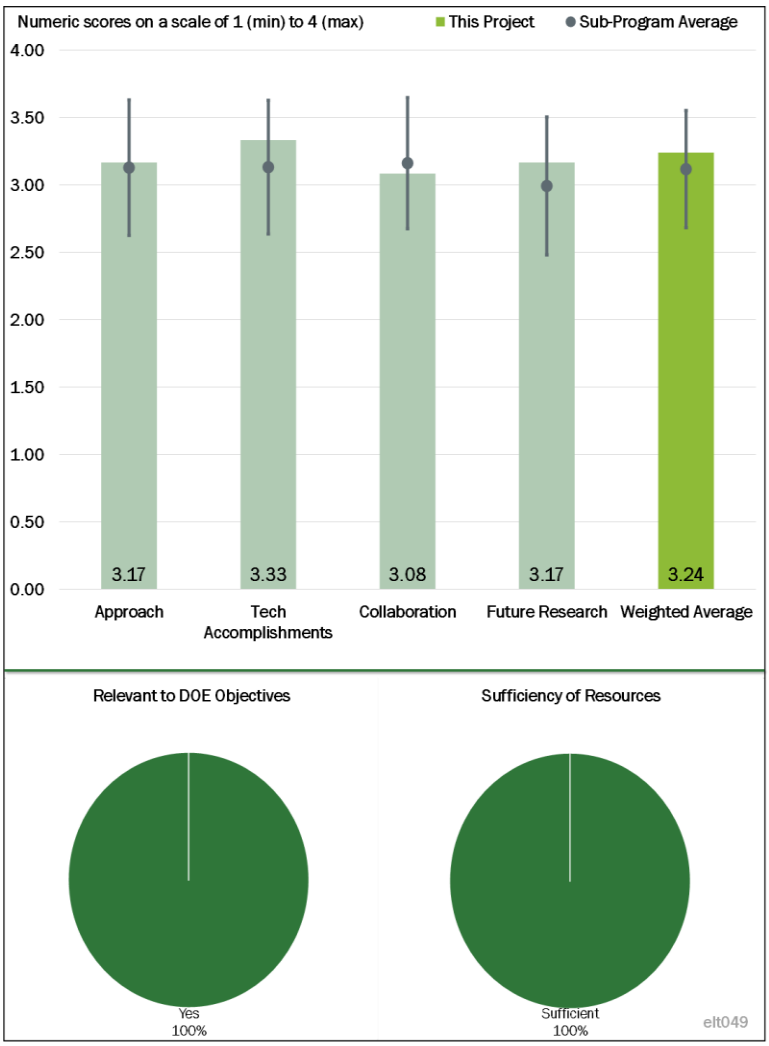

Figure 4-2 - Presentation Number: elt049 Presentation Title: Advanced High-Performance Computing (HPC) Multiphysics Modeling of Motors and Materials Principal Investigator: Jason Pries (Oak Ridge National Laboratory)

Reviewer 1:
The reviewer stated that the goal is to develop a high-performance computing (HPC) tool for electric motor design. The focus on multiphysics interaction is excellent, and the goal to develop open-source software will help to accelerate technology development to meet the DOE 2025 goals for electric motors.

Reviewer 2:
The reviewer observed a very good approach with taking advantage of HPC to overcome the challenging task to connect microscopic level of magnetic behavior to macroscopic level of electric machine behavior. Also, the reviewer highly appreciated making it accessible to the public by making it open-source. A possible consideration for the target model error of less than 5% is verifying the hardware measurement method as the baseline for validation of computational results.

Reviewer 3:
The reviewer stated that simulation tools are an important contribution to the advancement of magnetic materials. The tools will leverage the HPC capability at ORNL and other DOE laboratories. By making the software open source, many other people around the world will be able to contribute to the code, make improvements, and enable other magnetics researchers to develop new materials more easily.

Reviewer 4:
The reviewer said that the approach of high-fidelity modeling with great correlation and increased throughput would be a welcome addition to the tool boxes of all electromagnet (EM) designers. Metrics of less than 5% error (without tweaking) and 10 times the throughput improvement seem aggressive but are a welcome goal.

Reviewer 5:
The reviewer suggested that it may be better to compare the proposed method with the baseline or commercial software to demonstrate the advantage of the modeling method being explored, and set up criteria/projected performance goal for the success of modeling.

Reviewer 6:
The reviewer commented that the objectives for which the computational model needs to represent all nonlinearities and spatial features of the magnetic material are very ambitious. However, the presented slides do not sufficiently support the claims. The reviewer was seriously concerned about the demagnetization due to heat and its dependency on time (multiple runs result in more decay of magnetic quality), which is left vague here. Frequency dependency of the core losses are briefly mentioned without much elaboration on how it will be taken into account.

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

Reviewer 1:
The reviewer said that the project is in its first year. With that in mind, the accomplishments and progress are excellent.

Reviewer 2:
The reviewer observed good progress.

Reviewer 3:
The reviewer asserted that the progress looks good. The new software matches commercially available software well and, in some cases, eliminates some errors found in the commercial software.

Reviewer 4:
The reviewer remarked that very encouraging accomplishments were presented. The reviewer suggested also looking into the soft-magnetic material's magnetic-flux density (B) versus magnetic-field strength (H) (B-H) minor-loop validation with hardware measurements and frequency limit.

Reviewer 5:
The reviewer pronounced that it is early in the program and the scheduled goals milestones, while met, have not been challenging yet.

Reviewer 6:
The reviewer referenced prior comments. The reviewer stated that, also, there is an ambiguity in the 2018 funding start date of the project, which does not match the date of publication in the proceedings of the Energy Conversion Congress and Exposition (ECCE) 2017.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer described technical accomplishments and progress as excellent.

Reviewer 2:
The reviewer stated that the team is working with Ames Laboratory for data on hard magnetic materials and with NREL for thermal management research.

Reviewer 3:
The reviewer remarked that the list of collaborators seems to be sufficient and reasonable to advance this project.

Reviewer 4:
The reviewer commented that there was not a lot of collaboration evident yet nor valuable contributions. However, the reviewer noted that it was early in the project.

Reviewer 5:
The reviewer stated that collaboration with two other national laboratories has been established. It would be beneficial if some guidance or input from industry is included.

Reviewer 6:
According to the reviewer, there is good collaboration in magnetic material science with Ames Laboratory and in thermal modeling with NREL. It might be also good to obtain inputs from industry about motor design aspect.

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

Reviewer 1:
According to the reviewer, the team appears to have a good plan in place.

Reviewer 2:
The reviewer commented each goal, challenge, solution, and impact are identified in a straight-forward, linear fashion.

Reviewer 3:
The reviewer remarked that validation of the modeling assumes confident-enough hardware measurement results as the baseline. It would be better to have a plan for hardware-measurement confidence level improvement as well.

Reviewer 4:
The reviewer stated that the proposed future work for 2018 and 2019 seems to focus on the modeling of permanent magnet demagnetization and core-loss estimation. There is no mention of extending the nonlinear geometric constraint solver to motor types other than synchronous reluctance motors. If it is not already in the future plans, the reviewer suggested that permanent magnet type motors should be included in this part of the project.

Reviewer 5:
The reviewer noted that there is a need to mention the issues for the new model to address and how.

Reviewer 6:
The reviewer commented that the timeline indicates that the project extends to 2020. However, the research goals to be achieved in 2020 were missing.

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

Reviewer 1:
The reviewer commented that the improvement of electric motor design and optimization tools is essential for meeting the DOE 2025 goals.

Reviewer 2:
The reviewer remarked that electromagnetic behavior understanding and prediction are critical to meeting DOE objectives.

Reviewer 3:
The reviewer noted that this project is developing a multi-physics computing/modeling method to support electric motor designs, optimization, and virtual prototyping.

Reviewer 4:
The reviewer said that this project will allow for more detailed exploration of magnetic materials, allowing for further optimization and increased speed of new developments.

Reviewer 5:
The reviewer said that the objectives outlined here match well with the priorities of DOE.

Reviewer 6:
The reviewer stated that effective use of modeling and simulation gives the design teams the tools needed to experiment quickly and inexpensively on solutions to meet DOE Program 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 found the resources to be sufficient.

Reviewer 2:
The reviewer indicated that the provided funds seem to be sufficient to support the project's objectives.

Reviewer 3:
The reviewer had no concerns about the resources and stated that the project seems staffed at the correct levels

Reviewer 4:
The reviewer noted that the resources look sufficient in the modeling and HPC aspect. However, if there is a shortage for the model validation with hardware measurements, specific planning should be made with looking at further steps to take.

Reviewer 5:
The reviewer found it difficult to comment on the resources because the total project funding was not provided in the AMR presentation. The funding for 2018 only, $648,000, seems more than sufficient, considering there has not been any hardware development so far.

Presentation Number: elt054
Presentation Title: Drivetrain Performance Improvements Techniques
Principal Investigator: Gui-Jia Su (Oak Ridge National Laboratory)

Presenter
Gui-Jia Su, 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:
According to the reviewer, the approach is logical and systematic to build the platform, simulate/review, build validation, and validate.

Reviewer 2:
The reviewer commented that the approach is well thought out to identify the best possible switch scheme, derive the equations, simulate and compare results to today's switch schemes, and then test and validate with actual hardware. For both the simulated and actual hardware, the reviewer inquired if the project team could compare efficiency gains over a drive cycle or cycles as opposed to steady state. For this switch scheme, the reviewer asked what the effects are on the ripple voltage that the direct current (DC) link capacitor would see.

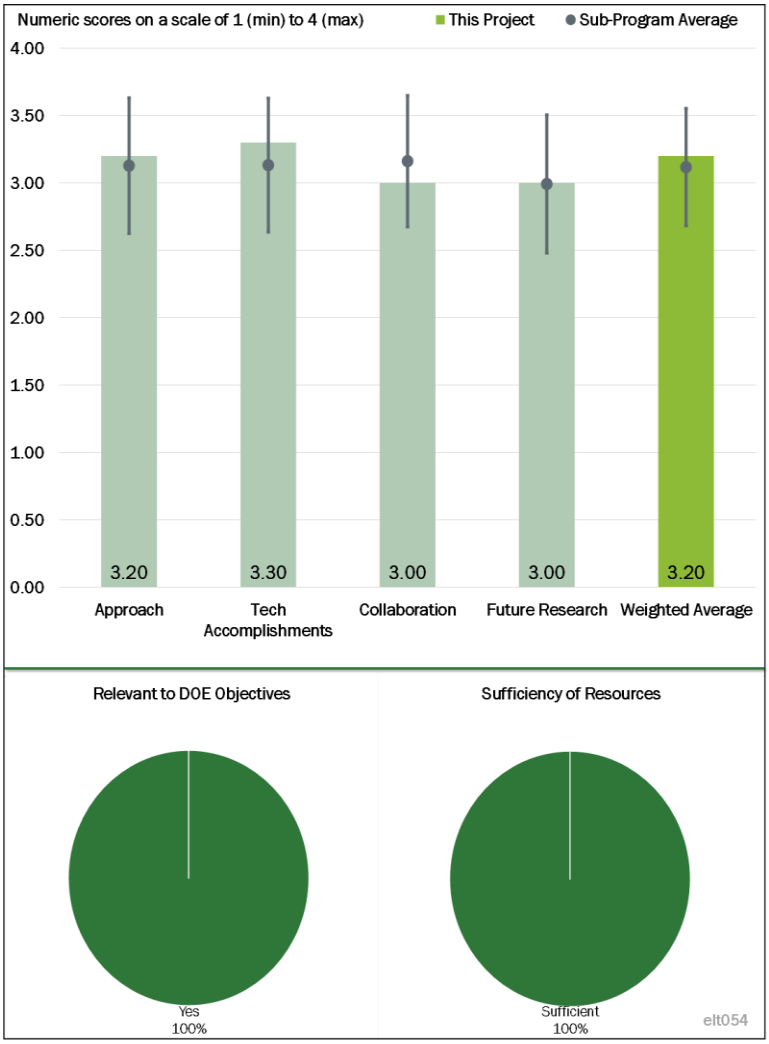

Figure 4-3 - Presentation Number: elt054 Presentation Title: Drivetrain Performance Improvements Techniques Principal Investigator: Gui-Jia Su (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer thought that the basic approach was sound, but assumes that the BMW and Camry loss maps are accurate and include a complete strategy of loss optimization. Complex control strategies (Six-Step, discontinuous pulse-width modulation, and reduced switching frequency based upon load and speed) may not be accounted for in the published loss maps.

Reviewer 4:
To the reviewer, this approach appears to be a promising method of reducing power loss in inverters. The reviewer expressed concern that the control algorithm will be difficult, though not impossible, to implement, especially when dealing with transients.

Reviewer 5:
The approach seemed promising to the reviewer. However, the assumptions made throughout the project are of some concern to this reviewer: Using averaging and linearization (neglecting the nonlinear behavior of the switching circuit), assuming only sinusoidal waveforms, and analysis of the power loss only for the steady-state regime while a good portion of losses occur during the transient. Furthermore, the clarity of the modulation technique needs some more work.

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

Reviewer 1:
The reviewer commented that the team has made good progress on modeling the control algorithm and inverter losses, as well as communicating with device manufacturers to understand the different loss mechanisms.

Reviewer 2:
Considering the simplifying assumptions, the reviewer remarked that the progress made thus far is good.

Reviewer 3:
The reviewer said that the project is on track; the simulated data look encouraging.

Reviewer 4:
The reviewer pronounced that work as good, thorough analytical work to this point and shows promise in theory.

Reviewer 5:
The reviewer stated that this is a relatively new project and progress is limited at this date.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted that the team has partnered with Wolfspeed and Rohm for better understanding the loss mechanisms in SiC power devices and with NREL on thermal management research.

Reviewer 2:
The reviewer found the project to be lacking basic benchmarking of loss optimization strategies currently being employed by OEMs. The reviewer suggested that patent searches and Institute of Electrical and Electronics Engineers (IEEE) paper searches may provide more information for setting goals and enhance project work.

Reviewer 3:
The reviewer commented that the collaboration part and the collaborators' tasks are not quite clear.

Reviewer 4:
According to the reviewer, partners are providing loss data for the switching devices; they do not appear to be actively involved with the program details.

Reviewer 5:
At this point in the project (early), the reviewer noted that the engagement and coordination with other institutions seems sparse. There are primarily discussions with SiC power module suppliers and seemingly no collaboration with NREL yet. Then, it is not clear what NREL's tasks and deliverables will be.

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 implementation of some of the proposed switching strategies will likely have implications on the vehicle (noise, vibration, and harshness of the traction motor is one example).

Reviewer 2:
The reviewer said that the team appears to have a good plan in place.

Reviewer 3:
The reviewer noted that the items listed for the future research show that the authors are well aware of the limitations and the path forward to address some of the challenges.

Reviewer 4:
The reviewer indicated that the project is well-planned, but alternate pathways are not mentioned. The project team will not know for certain if there is a problem until the team compares simulated results to actual results at the end of the program.

Reviewer 5:
The reviewer found the future work plan to be logical with appropriate decision points. However, the reviewer did not see barriers adequately discussed and/or mitigation for them.

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

Reviewer 1:
The reviewer stated that reduced losses through control strategies (improved efficiency) may allow for less battery and improved range for electric traction applications.

Reviewer 2:
The reviewer said that this project aims to reduce the thermal load from inverters, which could allow for higher power density and/or reduced thermal management requirements.

Reviewer 3:
The reviewer remarked that increasing efficiency at low speeds for the given range of torque is an important issue to be addressed.

Reviewer 4:
The reviewer observed that this approach improves efficiency and improves vehicle range, with little or no added cost to the vehicle. It also enables lower greenhouse gases, lowers dependence on foreign oil, and helps to enable the marketplace for electric drive vehicles (EDVs).

Reviewer 5:
The reviewer commented that an improvement in drive unit light-load efficiency pays dividends towards DOE goals, i.e., less consumed electrical power during lengthy times of drive cycle; less thermal management needed,

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

Reviewer 1:
According to the reviewer, this is just the start of the project, and the provided resources seem to be sufficient to support the execution of the project.

Reviewer 2:
The reviewer stated that resources appear sufficient and available.

Reviewer 3:
The reviewer noted that this small project is fully staffed and has adequate resources.

Reviewer 4:
The reviewer believed that there are sufficient resources to complete the project. OEM collaboration and/or benchmarking would provide more insight on this project.

Reviewer 5:
Resources appear to be sufficient for the given scope of the project, according to the reviewer. However, for deployment into the field, the reviewer suspected that a follow-on project will be needed for rigorously testing the control algorithm.

Presentation Number: elt071
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 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.

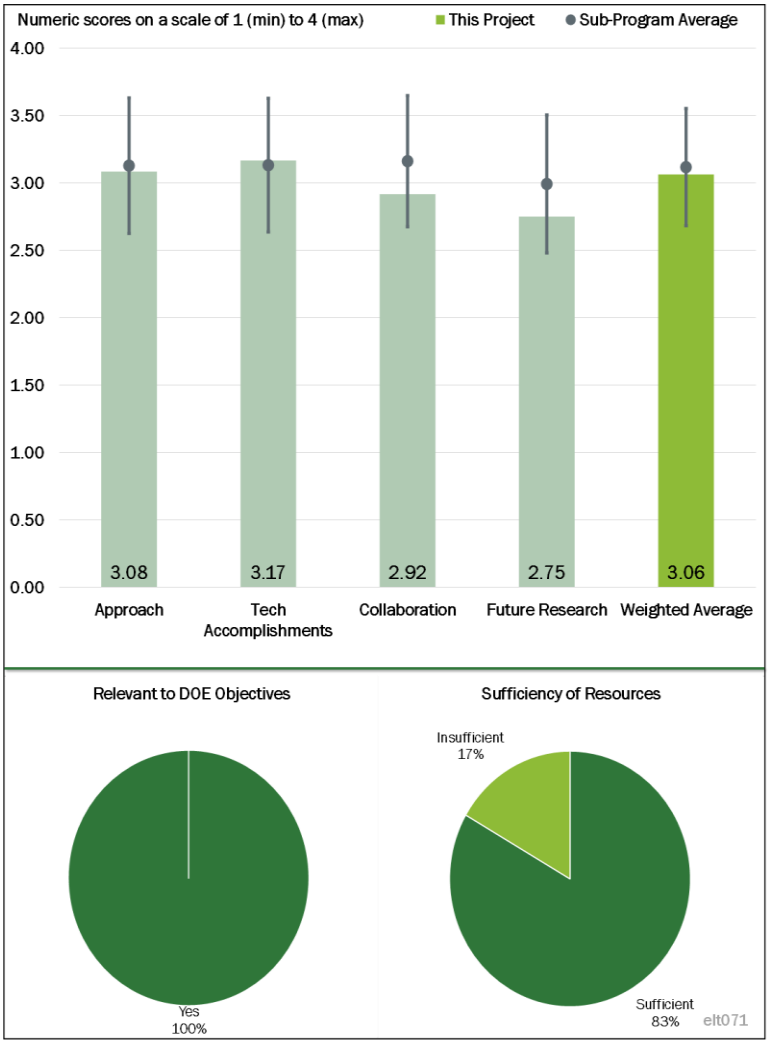

Figure 4-4 - Presentation Number: elt071 Presentation Title: Ultraconducting Copper Principal Investigator: Tolga Aytug (Oak Ridge National Laboratory)

Reviewer 1:
The reviewer pronounced the approach in terms of the area or research to be excellent. Copper is the source of loss and directly going after reduction of loss at the materials level makes sense. The theoretical potential of copper-carbon nanotubes (CNT) materials is impressive and therefore it should be developed. The reviewer commented that the approach is rightly focused on optimizing the production of the materials to maximize the improvements in performance.

Reviewer 2:
The reviewer stated that improved and high-performance conductors for electric machines and inverter interconnects are needed. This project supports DOE VTO 2025 targets for electric drive system needed for EVs, HEVs, PHEVs, etc.

Reviewer 3:
The reviewer said" the approach is well thought-out."

Reviewer 4:
The reviewer stated that the objective is to develop high-performance copper material using CNT resulting in higher electrical and thermal conductivity. The main focus so far has been on the basic material development, e.g., the multilayer architecture with copper film and CNT layers. This has to continue in the second half of the project, but additionally the reviewer suggested that the focus should extend more to how this new material can actually be used in a manufacturable electric machine. The reviewer questioned if a tape or foil winding is the right approach for a high-power traction motor.

Reviewer 5:
The reviewer thought that the baseline approach is sound as it relates to the science of copper deposition on CNT. The reviewer expressed concern regarding the eventual implementation of copper tape in the manufacturing of a motor. The reviewer would like to have seen more thought given to how this technology would eventually be implemented in conventional motor manufacturing.

Reviewer 6:
The reviewer noted that there are several organizations pursuing copper-CNT conductors. It is important to explain how this effort is different and how the proposed approach will lead to advantages in terms of manufacturing and/or properties.

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 team has developed a method to realize copper-CNT and has carried out experiments to measure electrical characteristics of copper-CNT.

Reviewer 2:
Given the amount of resources on this project, the reviewer indicated that excellent progress has been made.

Reviewer 3:
The reviewer pointed out that there has been significant progress in the development of the processing techniques for CNT deposition on copper tapes. However, the reviewer commented that the accomplishments with regard to materials property improvements compared to conventional copper are not very encouraging yet because the prototype samples show only a decreased resistivity of 5%-8%. The reviewer suggested that this has to decrease by a much larger extent in order to make this a viable solution for electric machines (tradeoff of increased cost versus decreased copper losses).

Reviewer 4:
The reviewer commented that the technical assessment stating reduction of copper mass in the motor is merely an electromagnetic design exercise. It does not consider how to manage insulation and interconnection technology using the CNT-copper tape. It merely takes advantage of the improved conductivity.

Reviewer 5:
The reviewer said that good progress has been made and the fact is that several samples have been tested. The 5%-8% reduction in resistivity shown so far seems fairly low for what is theoretically expected for a copper/CNT conductor and is not transformational. The reviewer proposed that more significant reduction in resistivity should be accomplished to ultimately justify this effort. Also, the reviewer believed that all the results presented were based on DC measurements. Because these conductors are intended for traction motors, which are typically high-frequency, investigation of alternating current (AC) losses in the copper/CNT conductor should be performed.

Reviewer 6:
The reviewer pronounced the initial improvement in electrical conductivity/resistivity over copper (5%-8% improvement over copper) to be a good start. The reviewer posited that it is obviously a long way from the theoretical value of 1.7, which may be approached but possibly not met due to the need for perfect conditions. Progress in thermal conductivity improvements was unclear to the reviewer. The process was also down-selected from three processes to two.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviews stated that collaboration is excellent due to the inclusion of several industry partners in the project.

Reviewer 2:
The reviewer noted that the DOE-ORNL led project team consists of multiple industries and DOE-NREL.

Reviewer 3:
The reviewer wanted to see more collaboration with production wire manufacturers as the reviewer did not believe that this technology will be well-executed if it cannot be implemented in motor grade wire.

Reviewer 4:
The reviewer remarked that most of the work is done within ORNL. More quantification of the motor performance benefits potentially working with OEMs is encouraged.

Reviewer 5:
The reviewer noted the collaboration with NREL and found it appropriate due to the close relevance of utilizing thermal management for further improving this idea. The reviewer indicated that there was also some industry input; more benefit may be achieved from multiple industry partners to guide development targeted at commercialization.

Reviewer 6:
The reviewer suggested that this project needs an industrial partner to be successful.

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

Reviewer 1:
The reviewer mentioned that the project team plans to keep improving materials and processes required to realize high-performance copper-CNT.

Reviewer 2:
The reviewer stated that the proposed future work is good from a technical perspective. But at some point, the reviewer said that the team has to provide an estimate of the cost impact. The tradeoff between increased cost and the expected performance benefit is crucial for this project.

Reviewer 3:
The reviewer remarked that ultra-conducting copper (UCC) is a great objective towards meeting 2025 DOE goals; however, the project needs a more realistic approach to implementation in production. Also, there needs to be a better understanding of the cost impact.

Reviewer 4:
The reviewer stated that it is important to target higher reduction of resistivity. It is important to investigate AC losses.

Reviewer 5:
The reviewer indicated that the future work focuses appropriately on optimizing processes to improve materials properties. The reviewer pointed out that there could have been more specific detail on how optimization will be explored and down-selected to one process. Also, the project did not provide targets for

electrical and thermal conductivity beyond the theoretical values of the material in the ideal state. Achievable or probable targets for these two parameters would have been helpful. The reviewer also said that plans for implementation in motors and scaled or representative models would be beneficial to this project.

Reviewer 6:
The reviewer suggested that the project team needs to have an industrial partner to understand all aspects that should be studied.

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

Reviewer 1:
The reviewer noted that the project is relevant as improved materials are needed to meet the DOE 2025 power-density targets in electric machines.

Reviewer 2:
The reviewer stated that low-cost and high-performance copper-CNT could be useful in projects funded by DOE VTO and could strongly support 2025 DOE VTO targets for electric drive systems

Reviewer 3:
The reviewer viewed this work as critical to the success of electric drive and other power electronics applications.

Reviewer 4:
The reviewer observed that copper-CNT conductors can have a significant impact on improving the efficiency and power density of traction motors.

Reviewer 5:
The reviewer believed that this project is very relevant. Motor performance improvement will be difficult, and cost reduction will be even more challenging. While the UCC promises significant improvement in conductivity, it was not clear to the reviewer that it will be cost effective. If the mass savings outweigh the additional cost of the UCC, it will support the DOE objectives.

Reviewer 6:
The reviewer commented that relevance to DOE targets is very high in terms of meeting power density requirements. Even if the project achieves half of the theoretical current density prediction, this will go a long way to meeting objectives. The reviewer posited that cost is the question as always at this stage of development so a qualitative evaluation of material and process cost would be helpful.

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

Reviewer 1:
The reviewer believed that the resources are adequate.

Reviewer 2:
The reviewer indicated that the allocated budget is sufficient for the proposed scope.

Reviewer 3:
The reviewer commented that the funding of $300,000 per fiscal year is potentially on the low end for a project that involves manufacturing hardware samples, especially considering the complicated processing techniques.

Reviewer 4:
The reviewer suggested that more industry partners may be helpful in terms of guiding development for eventual implementation.

Reviewer 5:
The reviewer asserted that the project team should explore more applications of copper-CNT beyond its use in motors. This could require the PI to approach industries and academic institutes willing to provide application platforms for copper-CNTs, which would put application-specific resources at the disposal of the PI.

Reviewer 6:
According to the reviewer, significant resources need to be added to this project for it to contribute towards program objectives. This work has implications across the board.

Presentation Number: elt074
Presentation Title: Non-Rare Earth Electric Motors
Principal Investigator: Tsarafidy Raminosoa (Oak Ridge National Laboratory)

Presenter
Tsarafidy Raminosoa, 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 stated that it would have nice to describe why rotary transformer excitation was chosen as the wound-rotor excitation method.

Reviewer 2:
The reviewer described the approach involving the development of a rotating transformer as a delivery mechanism for field current to a wound-field synchronous machine (WFSM). The approach also involves utilization of copper-CNT material development from another program to downsize/increase power density to the target of 50 kilowatt per liter (kW/l). In addition, a parallel effort involves design of an AlNiCo magnet-based motor using enhanced AlNiCo material from Ames. The reviewer stated that the rotating transformer may increase reliability for WFSMs by eliminating the wear elements in the commonly used slip rings for this type of machine. However, it is unclear to the reviewer how the rotating transformer will help meet cost and power-density goals. Copper-CNT material seems to be the primary approach for helping WFSM architecture to meet power density and cost goals. It is also unclear to the reviewer how the AlNiCo motor will help meet power-density goals given that the target magnetic properties are not better than state-of-the-art NdFeB motors that currently are not meeting power density goals of 50 kW/L. Though AlNiCo may help meet cost targets, only if cobalt (Co) prices decrease with respect to NdFeB, it did not seem to the reviewer that the elements of this project can be combined to collectively provide cost, reliability, and power-density targets; however, each individually could help meet components of the targets. The reviewer stated transformer-reliability, AlNiCo-cost, and Cu-CNT in WFSM equals power density.

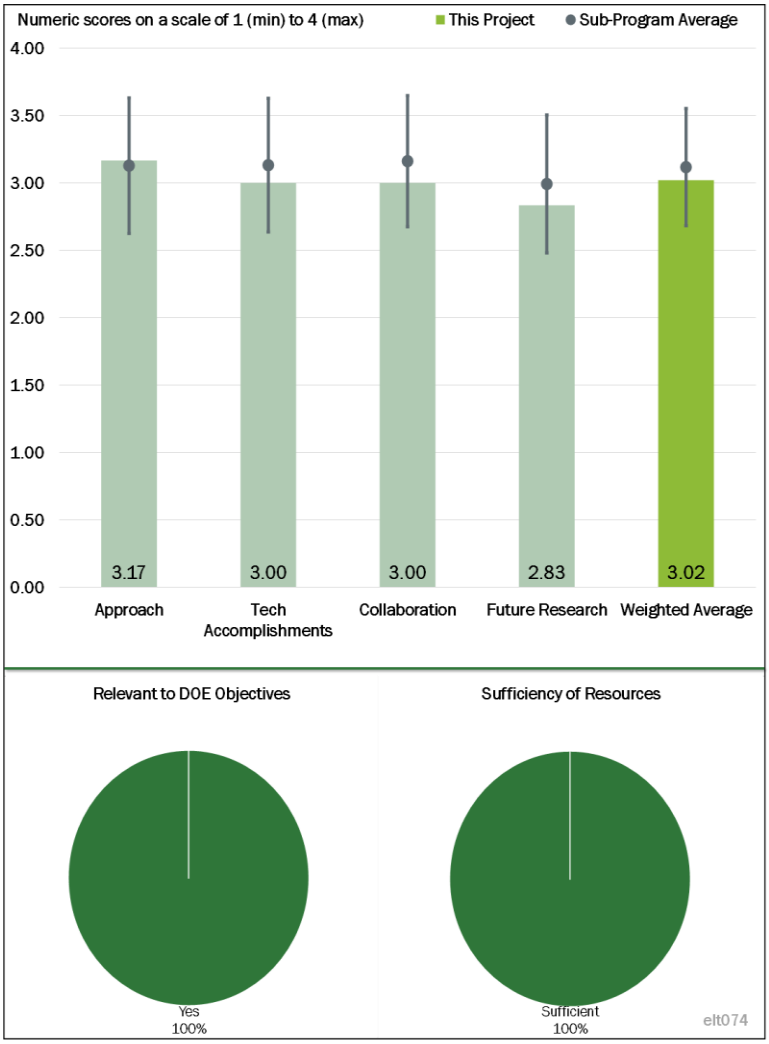

Figure 4-5 - Presentation Number: elt074 Presentation Title: Non-Rare Earth Electric Motors Principal Investigator: Tsarafidy Raminosoa (Oak Ridge National Laboratory)

Reviewer 3:
This reviewer stated not applicable.

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 questioned the rotary transformer design by asking how the design verification with hardware test will be carried out. The reviewer also wanted to know whether, for ultra-conducting copper, both the baseline copper foil wound machine and the ultra-conducting copper foil machine would be constructed and tested for side-by-side comparison.

Reviewer 2:
The reviewer remarked that the go/no-go decision for transformer plus WFSM meeting power-density targets seems unlikely due to a predicted size/weight reduction of only 6%-7% based on copper-CNT material.

Reviewer 3:
This reviewer stated not applicable.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented that NREL, Ames, and ORNL have excellent people and capabilities to perform the work required. No industry partner was noted but one may be helpful in providing commercialization expertise.

Reviewer 2:
The reviewer found the collaboration with other national laboratories to be good. The reviewer noticed that no industry partner is stated and suggested that it might be a good idea to have industry inputs during this activity.

Reviewer 3:
This reviewer stated not applicable.

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:
It was unclear to the reviewer if the team will build and test both the AlNiCo motor and WFSM motors or just simulate. Otherwise, the future plans seemed good in terms of demonstrating the concepts.

Reviewer 2:
The reviewer asked about whether the compensation capacitors need special precision. If yes, then the reviewer wanted to know how that would affect the cost. The reviewer inquired about whether the compensation capacitors' long-term characteristics degradation would affect the rotary transformers' power transfer performance. If yes, then the reviewer asked whether that would be quantified. The reviewer questioned how one can compare the rotary transformer power transfer and the capacitive power transfer discussed in project ELT092. The reviewer appreciated hearing discussions of pros and cons. The reviewer wanted to know if a permanent magnet machine with AlNiCo also would be prototyped and tested with high-temperature.

Reviewer 3:
Set up criteria/projected performance goal for success was indicated by this reviewer.

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

Reviewer 1:
The reviewer responded, yes.

Reviewer 2:
The reviewer remarked that both the alternative permanent magnet (AlNiCo) and the wound-rotor machine are potential candidates for alternatives to existing, heavy rare-earth permanent magnet machines.

Reviewer 3:
Although all of the elements of the project have some relevance to the 2025 goals, it was difficult for the reviewer to see how any one of them or a combination of them could allow the goals to be met. It purely depends on the development progress of copper-CNT, where so far, a 6%-7% size reduction has been attained, significantly more is needed.

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

Reviewer 1:
It appeared to the reviewer that the resources are appropriate to execute the scope.

Reviewer 2:
Currently, resources looked sufficient to this reviewer. However, it was not quite clear at this point for the reviewer that wound-rotor machines with both conventional copper and ultra-conducting copper and also AlNiCo permanent magnets (three prototype machines in all) will be constructed for hardware testing.

Reviewer 3:
This reviewer stated not applicable.

Presentation Number: elt075
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 seven reviewers evaluated this project.

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

Reviewer 1:
The reviewer said that the approach is good, the steps are logical, and the project is certainly feasible.

Reviewer 2:
The reviewer agreed with the approach to focus on the thermal interfaces; these are tough problems to solve.

Reviewer 3:
The reviewer stated that new and advanced materials are needed for aggressive heat-transfer required in power-dense electric machines. The project team has identified materials and has carried out thermal characterization.

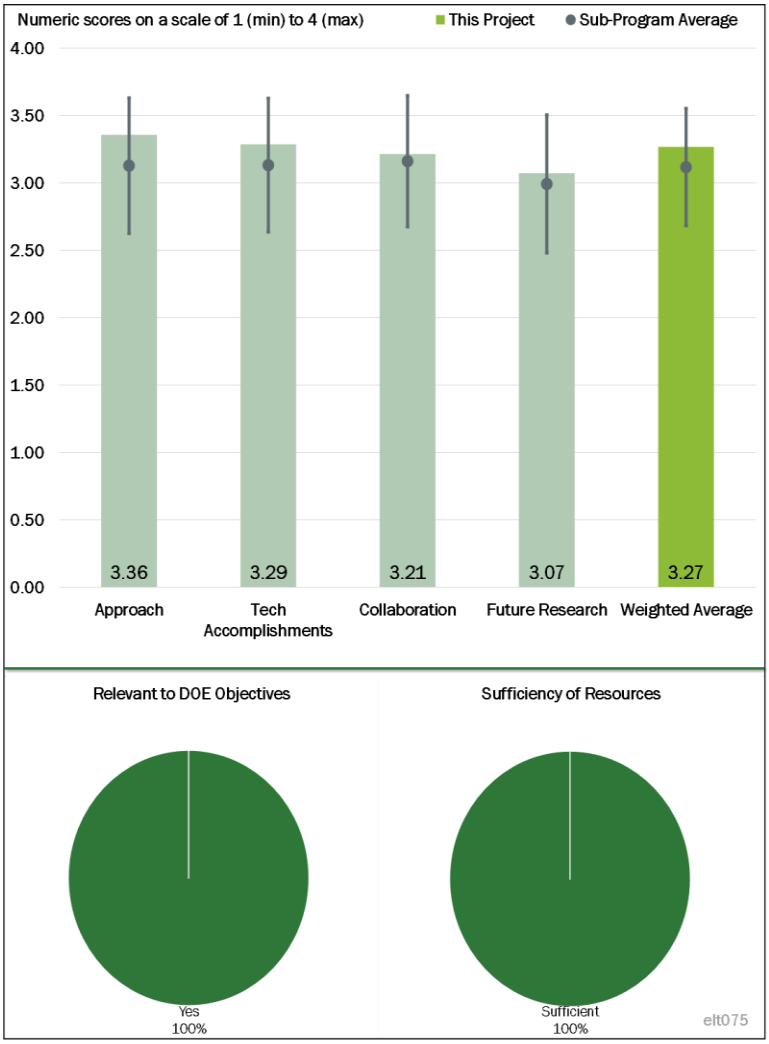

Figure 4-6 - Presentation Number: elt075 Presentation Title: Electric Motor Thermal Management Principal Investigator: Kevin Bennion (National Renewable Energy Laboratory)

Reviewer 4:
The reviewer pointed out that the key technical barriers to increasing motor power density and lifetime while reducing cost are related to materials and modeling. The thermal conductivity of the base metals, the epoxies and fillers, and especially the windings drive the amount of material needed to create the required magnetic field. The reviewer stated that higher electrical and thermal conductivity windings, for example, would mean smaller wires and thus significantly reduced cost, size, and weight.

The reviewer observed that one element of this project focuses on developing material performance characterization techniques, an area not currently well-covered in the literature, in order to gain the accurate material parameters needed to speed up design (e.g., fewer iterations). These techniques, according to the reviewer, will also permit the insertion of new materials to reduce the thermal resistance of the motor, thereby increasing the power density. The approach to addressing these issues is well-designed and focuses on thermal interface resistance, an area equal in importance but less well studied than bulk conductivity owing to the

difficulty in measuring it. Thermal interface resistances at the stator-to-case, line-to-stator, winding-to-liner, and cross-slot winding are assessed.

The reviewer asserted that another element focuses on the development of active motor cooling technologies to take advantage of the new motor materials. These include various forms of jet impingement and direct cooling with a variety of fluids, including automatic transmission fluid (ATF). This is also well-designed, looking at the effect of a variety of impingement parameters including incidence angle, distance from target, and fluid temperature.

Reviewer 5:

The reviewer noted that the objective of this project is materials and interface thermal characterization and evaluation of motor systems impact with active cooling. The reviewer found the measurement of lamination thermal contact resistance to be of value. For the winding thermal characterization, the focus has been on stranded winding although the industry is mainly switching to bar winding for traction motors. The reviewer suggested that it would be good if the project could be extended to cover this type of winding.

Reviewer 6:

The reviewer pronounced the project approach to be good in terms of quantifying many factors that can impact the design/prediction of the motor's thermal management system. In order to achieve a 10-fold improvement in power density, very novel thermal management schemes need to be proposed/developed. So far, the reviewer said that the project has been focused on quantifying existing materials and thermal management techniques.

Reviewer 7:

The reviewer indicated that the approach involves improving key parameters for motor thermal modeling as well as evaluating new thermal approaches for improved performance. Both are needed to meet targets. According to the reviewer, this area of work will be key in meeting the new targets. It would be good to see some other approaches to improve thermal performance beyond impingement of oil and proposed design of experiments to evaluate.

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 there was excellent progress reported, including publications in the technical literature.

Reviewer 2:

According to the reviewer, the team at NREL has successfully characterized many motor thermal impedance areas that have eluded motor designers (contact resistances of various materials). This work will benefit industry greatly and forms the basis for making improvements from industry standards.

Reviewer 3:

The reviewer stated that certainly having the motorettes in the future will enable validation of the technical accomplishments and progress.

Reviewer 4:

The reviewer mentioned that significant progress has been made in the first year of this program in the development of methods and models for the measurement of cross-slot winding thermal resistance, stator lamination thermal resistance, and stator-to-case thermal resistance. In addition, the thermal and mechanical properties of magnet materials were measured. The reviewer stated that these values were then used to determine the thermal resistance of a series of slot windings, those windings when bonded to a slot liner, and the slot liner when coupled into a segment of the stator. Furthermore, progress was made on quantifying the effect of key parameters on heat transfer in orifice jet impingement, fan jet impingement, and direct cooling

with ATF. This work showed increases in heat transfer coefficient with surface temperature and nozzle jet velocity, according to the reviewer.

Reviewer 5:
The reviewer acknowledged that the project is progressing according to plans. The only issue the reviewer had is that the overall work is not challenging the existing knowledge base or progressing it much further. However, they are doing what they said they would do, sticking to the schedule, and publishing their findings.

Reviewer 6:
The reviewer commented that it seems as if a lot of progress has been made, but the actual AMR presentation is very light in content in that regard. Several references to publications have been provided but showed very little results in the presentation. The reviewer did not think that it should be the reviewer's job to find these publications in order to evaluate the progress and accomplishments. The reviewer suggested that this should be improved for next year's AMR.

Reviewer 7:
The reviewer pronounced the progress made to be good, but there is still the big missing piece of quantifying the impact of the more accurate materials/cooling methods on the performance of an actual motor design/prototype. Also, quantification of spray cooling on the insulation life is still another key piece.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
It was apparent to the reviewer that there was excellent bi-directional communication with partners in this project. Collaborators presented problems and NREL analyzed, experimented, and shared results and methods.

Reviewer 2:
The reviewer said that strong, well-coordinated collaborations were exhibited among the internal and external project partners. ORNL was active in the cross-slot windings work and the development of no rare-earth or reduced rare-earth motors. Ames collaborated on the magnetic material properties work. Motor industry suppliers and drive-line fluid suppliers provided fluid properties, insulation material properties, and boundary conditions for simulation and experimental work.

Reviewer 3:
According to the reviewer, there was excellent work across the national laboratories and partners.

Reviewer 4:
The reviewer stated that there was good collaboration with other national laboratories as well as industry.

Reviewer 5:
The reviewer remarked that the NREL-led team has two DOE laboratories and supplier companies for materials required for the motor project. The team and collaboration look adequate to the reviewer.

Reviewer 6:
The reviewer found collaboration with Ames Laboratory to be good and seems adequate. It was not clear to the reviewer what others ("Motor industry representatives") are contributing to the project.

Reviewer 7: 9-40
According to the reviewer, the project PI claims collaboration and coordination with suppliers from motor and fluid industries but provided no company names or details. The reviewer asked what the result has been with these collaborations. Similar to the Accomplishments and Progress section, the AMR presentation does not provide much information and this should be improved next year.

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

Reviewer 1:
The reviewer remarked that the proposed work will help quantify the impact of the characterization done so far on a small system resembling a motor.

Reviewer 2:
According to the reviewer, the PI clearly outlined the remaining challenges and barriers in both materials and interface characterization and motor systems active cooling. This included additional reliability work on aging of fluids and materials to support increased lifetime targets; alternative motor designs, including alternative winding configurations, along with methods to improve convective cooling and the use of better fluids. Proposed future research will focus on modeling the "motorette" and material and fluid characterization.

Reviewer 3:
The reviewer asserted that the project team has identified tasks targeted for materials characterization and active cooling of electric motors; these are quite appropriate for successful execution of this project.

Reviewer 4:
The reviewer pointed out that there may be some new developments in the global supply of electric machines in Europe, particularly with the Volkswagen Group's new emphasis that may produce some new thermal management techniques and materials.

Reviewer 5:
The reviewer reported that future planning was good in terms of set up for further experimentation for evaluation of materials and techniques. The reviewer suggested that there may be a need to definitively select new materials for evaluation, develop implementation for the materials, and evaluate more active cooling techniques other than oil-based cooling.

Reviewer 6:
The reviewer found not much content was provided for future research. The one slide shows very general wording and is more or less a copy of a slide under Accomplishments and Progress. The reviewer asked what the specific plan is for future work.

Reviewer 7:
The reviewer stated that the Proposed Future Research looks like business as usual and does not seem to advance the state of the art.

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

Reviewer 1:
The reviewer stated that the project is relevant because the improved understanding of thermal characteristics of electric motors enables better designs.

Reviewer 2:
The reviewer commented that improved thermal management is a key enabler for meeting DOE's motor performance targets.

Reviewer 3:
The reviewer said that this effort has great relevance. The only chance of meeting the new power-density requirements is to make very large improvement in thermal management for both motors and inverters.

Reviewer 4:
As most power systems are thermally limited, the reviewer remarked that research on the passive thermal resistance of materials and the heat transfer potential of active motor cooling schemes with various fluids is critical to achieving the DOE goals of a 10-fold increase in motor power density, two-fold increase in lifetime, and 53% decrease in cost. Better cooling can increase reliability by avoiding failures due to temperature cycling and thermal overstress while improved thermal management can allow the motor to run with less material, thereby reducing cost, size, and weight and increasing power density.

Reviewer 5:
According to the reviewer, higher power and power density will continue to challenge thermal design of machines.

Reviewer 6:
The reviewer commented that advanced cooling for electric machine is a must to accomplish electric drive system's power density target set for DOE VTO.

Reviewer 7:
The reviewer asserted that electric machine cooling is a critical component to efficient and cost-effective electric and hybrid vehicle design and future success. The reviewer would like to have seen the project stretch beyond what may generally already be known and done in industry today.

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 sufficient, considering the cost of building test set-ups.

Reviewer 2:
The reviewer said that resources are sufficient based on proposed scope.

Reviewer 3:
The reviewer indicated that resources seem appropriate and well managed to achieve the stated milestones.

Reviewer 4:
The reviewer found that the project team has the necessary resources.

Reviewer 5:
The reviewer remarked that the project is staffed and funded to hit the scheduled milestones and do so on time.

Reviewer 6:
In terms of research, the reviewer pronounced the resources in the project to be excellent. The program could benefit from more industry partners for consultation and assistance in implementation for the new thermal techniques.

Reviewer 7:
The reviewer was unable to evaluate in detail; the overall magnitude of funding seems reasonable.

Presentation Number: elt077
Presentation Title: Innovative Converters and Chargers
Principal Investigator: Veda Galigekere (Oak Ridge National Laboratory)

Presenter
Veda Galigekere, 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 liked the idea of using the traction inverter as part of the wireless power transfer system. The team pointed out one integration issue: increased usage and reduced reliability of the inverter. The reviewer inquired whether there are there other integration barriers, such as increased electromagnetic interference due to high-frequency current in the leads between the coil and the inverter.

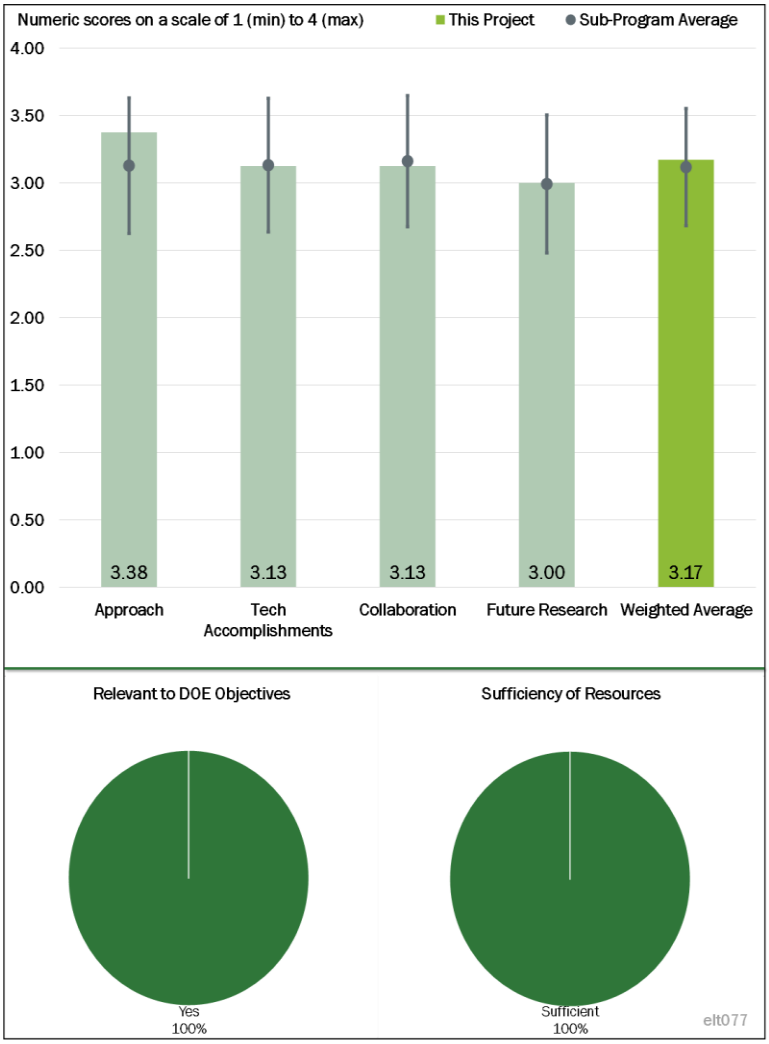

Figure 4-7 - Presentation Number: elt077 Presentation Title: Innovative Converters and Chargers Principal Investigator: Veda Galigekere (Oak Ridge National Laboratory)

Reviewer 2:
The reviewer remarked that addressing increased power density, planar vehicle assembly, and scalability of wireless charger help to lower cost and enable the technology. The project is well designed and feasible.

Reviewer 3:
According to the reviewer, utilizing the existing traction-drive inverter and DC-DC converter for wireless charging are good candidates for a cost-effective realization of wireless charging. The reviewer stated that explicitly itemizing potential issues and roadblocks in implementing such an approach in commercial vehicles from practical viewpoints would have been nice. The reviewer gave parenthetic examples of issues and roadblocks, such as whether any switching-over mechanisms are necessary between the motor and the wireless charge secondary and whether any extra components are needed for the switching over. In addition, the reviewer parenthetically mentioned that the power semiconductor devices chosen for the best performance for the traction inverter may or may not be a good choice for wireless power transfer, in particular if the switching frequency of the traction inverter and that of the wireless charger secondary side are very different.

Reviewer 4:
Not applicable was indicated by this reviewer.

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

Reviewer 1:
The reviewer noted that the team has made good progress on the development of a model and prototype of the proposed system.

Reviewer 2:
The reviewer remarked that the team is focused on their work and appears to be on target.

Reviewer 3:
The reviewer recognized the progress as good, but it looked to the reviewer that the secondary-side hardware is not really a traction-drive inverter connected to the traction motor. The reviewer's understanding is that one of the key points of this project is to integrate with the traction inverter going beyond the laboratory bench. Hence, staying within the proof-of-concept by not using the motor-connected traction-drive inverter could be a value-lessening factor of this project.

Reviewer 4:
This reviewer stated not applicable.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer said that there is good collaboration with another national laboratory and an industry partner. The reviewer suggested that it would have been nice if the collaboration and coordination were described more specifically about who does what (the slide has more than half empty space).

Reviewer 2:
The reviewer commented that the team is working with NREL on thermal management research and with Lear for project feedback.

Reviewer 3:
The reviewer noted that NREL is shown as a partner, but there is no work in the presentation attributed to NREL at this time. The team from ORNL and Lear appears to be working well. The reviewer stated that it would have been useful for the team to have an OEM representative for the vehicle of choice to help with integration and to help to minimize accessibility issues.

Reviewer 4:
This reviewer stated not applicable.

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

Reviewer 1:
According to the reviewer, the team appears to have a good plan in place.

Reviewer 2:
The reviewer found the scalability evaluation of 50 kW to be good, but asked if "evaluate" means hardware prototyping or just a calculation-based estimation. The reviewer requested clarification.

Reviewer 3:
The reviewer stated that the remaining issues need to be addressed as well as how.

Reviewer 4:
The reviewer pointed out that there is no mention about the planar vehicle assembly; otherwise, the proposed future work on scalability and building the wireless fast-charger are logical next steps.

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

Reviewer 1:
The reviewer reported that cost-effective wireless charging for higher power rating is one of the relevant topics.

Reviewer 2:
The reviewer explained that this project has the potential of integrating a wireless power-transfer system with the existing traction inverter, thereby reducing the size and cost of the wireless power system.

Reviewer 3:
Meeting the DOE Electrification Technologies (ELT) 2025 targets on efficiency and increased power density while reducing costs helps to enable EDVs and lower our dependence on foreign oil, according to the reviewer.

Reviewer 4:
This reviewer stated not applicable.

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

Reviewer 1:
It looked to the reviewer that the resources are currently sufficient considering the proposed hardware prototyping plan.

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

Reviewer 3:
The reviewer pointed out that the project team may need the resources of an OEM to help with integration of their system. Otherwise, the resources are sufficient.

Reviewer 4:
The reviewer said not applicable.

Presentation Number: elt078
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 seven reviewers evaluated this project.

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

Reviewer 1:
The reviewer commented that the use of a finned heat spreader significantly improved thermal performance. Using ATF as the device cooling fluid is a good idea to reduce cost in the system.

Reviewer 2:
The reviewer thought that the basic approach is sound, but did not believe that two-phase cooling would be acceptable to automotive OEMs.

Reviewer 3:
The reviewer suggested that fixed assumptions about volume breakdown could be made a little more flexible so that unknown factors can be taken into account. The team could state a few more specific ideas in the approach regarding the potential ATF use.

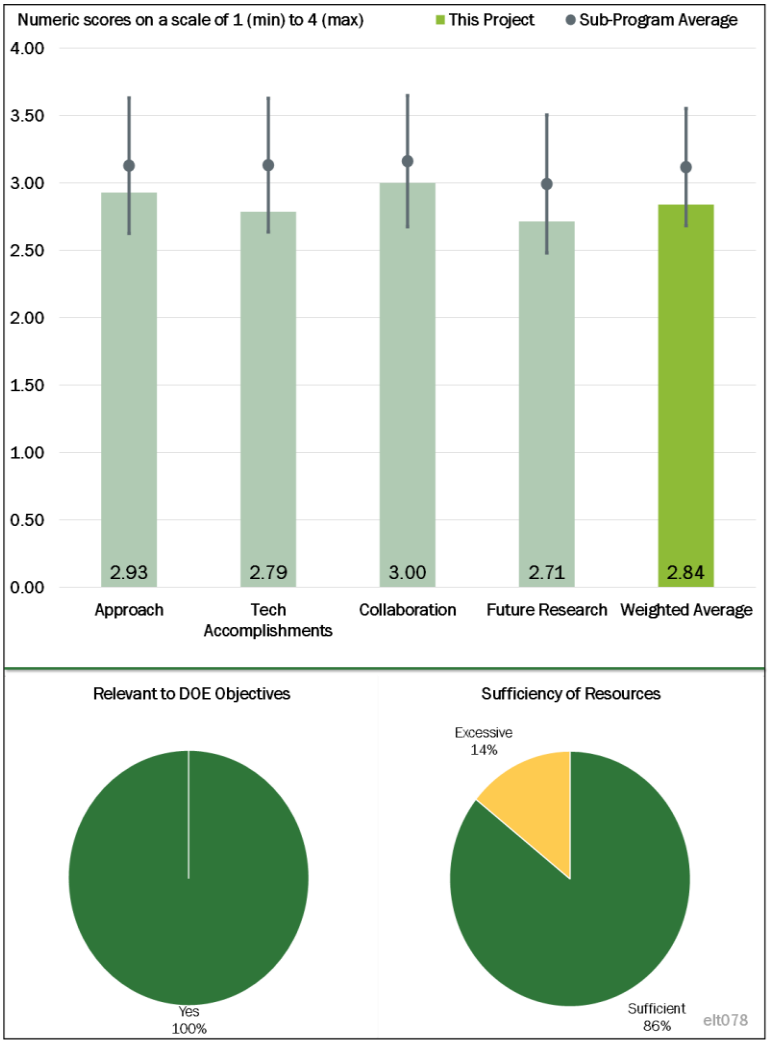

Figure 4-8 - Presentation Number: elt078 Presentation Title: Power Electronics Thermal Management Principal Investigator: Gilbert Moreno (National Renewable Energy Laboratory)

Reviewer 4:
The reviewer stated that the approach is well designed and clearly feasible as it focuses on making innovative improvements to existing technologies and integrating them to create novel solutions that meet the DOE targets. The study is initially limited to single-phase cooling since, if single phase is sufficient to achieve the needed cooling at reasonable velocities (less than 5 meters per second [m/s]), there is less incentive to move to the more complex two-phase approaches. Also, single-phase systems are easier to seal, thus addressing the sealing challenge. Next, the reviewer noted that the approach evaluates slot jet versus circular jet cooling to address the challenge of low heat transfer for laminar flow of dielectric fluids, finding that slot jets were as good as or better than circular jets at the typical nozzle diameters. However, because neither jet could reach the needed cooling metrics, the reviewer commented that finned surfaces were combined with slot jets to reduce thermal resistance. The reviewer opined that this adds an additional challenge of making sure sufficient fluid is being wicked down the fins. Using lower viscosity dielectric fluid is planned to assist with this. The eventual goal is to move to low-cost ATF to increase efficiency and reduce pumping power, rather than to introduce a

separate system of pumps, reservoirs, and fluid for a separate power-electronics cooling loop. The reviewer remarked that ATF is dielectric, already qualified for automotive use, and permits motor-inverter integration. The team clearly stated the steps to achieve this goal.

Reviewer 5:

The reviewer remarked that the power density target calculation was missing a considerable portion of inverter volume, electromagnetic compatibility filer, bus bars, current sensing, coolant channel volume, connectors, wire harness, and housing. With respect to comparing potential cooling strategies, the reviewer expected a detailed Pugh matrix comparing more than just one aspect of the potential cooling strategy. All that was shown was a comparison of thermal performance. Also, the reviewer stated that there are other cooling strategies that were not considered in the design space. Considering only direct-bonded copper baseplate- and device- cooled was described by this reviewer as a shallow approach.

Reviewer 6:

The reviewer remarked that the feasibility of the proposed approach, i.e., a fluid in the vicinity of all devices, needs more elaboration. Practicality of the method where fluid needs to be pumped through the power electronic devices, while addressing the sealing issue is a concern that requires clear justification.

Reviewer 7:

The reviewer asserted that the inverter model includes gate drives, a control board, a capacitor and power devices. But, there is only a reference to the cooling of the power devices and the capacitor and nothing said about the thermal gradient within the inverter. The reviewer asked about what happens thermally to the gate drives and the control board. The reviewer found the reference to the capacitor volume decrease to be interesting but that reference does not state the value of capacitance or the technology of the capacitor that is reducing in size. Perhaps defining the value of capacitor needed for the inverter would be more appropriate. Once that happens, a capacitor that could survive at 125°Celsius (C) and still fit in the box could be selected. There are automotive-grade components for the control board and gate drive board that will also survive at 125°C. This could help with designing the cooling system. The reviewer asked what the author's assumptions are about the ambient environment around the inverter.

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

Reviewer 1:

According to the reviewer, results of the thermal simulations look promising. The approach should enable the system to reach the power density goal.

Reviewer 2:

The reviewer stated that the progress is acceptable based on the project objectives.

Reviewer 3:

The reviewer asserted that it is certainly great accomplishments in dielectric coolant selection, modeling, and thermal design. It would however have been even better, the reviewer opined, if the following were identified: the unknown factors and the critical questions to be answered in eventually using ATF as the coolant because ATF is in the scope of the final coolant selection both in the approach statements and the technical accomplishment statements.

Reviewer 4:

The reviewer mentioned that significant progress has been achieved in the first year of the program toward the 100 kW/l power-density target. This has included conceiving the cooling architecture, developing thermal models for single-phase jet impingement cooling, evaluating slot versus circular jets for a variety of jet parameters (e.g., velocity, nozzle size), and evaluating using finned structures to improve heat transfer. The

reviewer noted that additional progress on the cooperative research and development agreement (CRADA) was achieved but not reported on.

Reviewer 5:
The reviewer commented that some proof of concept in theory have been presented, which mainly includes simulation results. However, no experimental results are presented.

Reviewer 6:
The reviewer simply did not see sufficient work products that would equate to the amount of funding in FY 2017 ($493,000).

Reviewer 7:
The reviewer reported that it would have been helpful to see the thermal gradient not only on the power devices but also on the gate drive and the control board. If there is an assumption of 125°C operation capability for the capacitor, gate drive, and control board, then the reviewer asked how that would affect the cooling design.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer remarked that the team is working with several organizations to ensure the project progresses in a timely manner and is relevant to the industry.

Reviewer 2:
The reviewer noted that reasonable collaboration and partnership have been reported.

Reviewer 3:
According to the reviewer, the team seems adequate and qualified.

Reviewer 4:
It seemed to the reviewer that collaboration with the team is acceptable.

Reviewer 5:
The reviewer found that there was good collaboration both with another national laboratory and industries. Regarding the above-mentioned ATF questions also, such collaboration could be made.

Reviewer 6:
The reviewer said that there is good collaboration and coordination among the internal team members at NREL and the liaison with ORNL (Tim Burress). These strong ties are a key element of the success of the program. The reviewer noted that there was less evidence of strong direct involvement from the external partners to date. The project includes both the primary effort of thermal management technologies to enable a power density target at 100 kW/l, but also a related CRADA on two-phase cooling for a high packaging density, planar inverter. John Deere is actively contributing to the related CRADA. However, the reviewer stated, the level of participation is not clear because this presentation focused on the primary effort. Elementum3D is to provide 3-dimension (3-D)-printed metal parts, presumably for the fins as well as other elements of the cooling system. However, the fins are currently produced by skiving. The reviewer hoped that these entities will become more involved with the program in the coming year.

Reviewer 7:
It was not clear to the reviewer what John Deere, Elementum3D, and ORNL have contributed.

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 appears to have a good plan in place.

Reviewer 2:
According to the reviewer, the PI recognizes the key barriers to the realization of the proposed technology and has developed a carefully designed approach for future research to address the barriers. This approach includes characterizing the properties and evaluating the cooling potential of not just the preferred solution of ATF, but also a range of other dielectric coolants in case ATF is too viscous or cannot achieve the cooling targets. The reviewer remarked that the approach also includes evaluating other techniques including phase-change cooling (CRADA). Other key aspects include conducting module-scale simulations to determine the optimum cooling scheme and developing cooling solutions for transient conditions. Go/no-go decision points are included.

Reviewer 3:
The reviewer opined that the decision to move towards single-phase cooling is directionally better than two-phase cooling. Previous DOE projects studied jet impingement cooling and have shown both benefits and significant challenges. Pumps and filters add cost and complexity that would typically not be acceptable to the OEMs.

Reviewer 4:
The reviewer agreed that the approach is good. The project team should verify that the 65°C inlet temperature for transmission coolant is correct and look at the possibility that the 85°C rating of the capacitor could be changed to 125°C; that could help the cooling system design.

Reviewer 5:
The reviewer called this a nice, ambitious future research proposal. It would have been nice to be clear about what the author exactly meant by "experimental demonstration." Also, it would have been nice to hear more about "Evaluate using ATF" and "phase-change" in the last two bullet points in Slide 19. The reviewer asked if the future research includes any hardware "evaluation."

Reviewer 6:
The reviewer remarked that the decisions do not appear to have sufficient depth in evaluation. From what can be seen, the project has embarked on evaluating a cooling method on a very incomplete power-module design concept. There needs to be a viable power-module design concept of sufficient depth as to be viable before evaluating cooling methods.

Reviewer 7:
The future research and the path forward were not quite clear to this reviewer. The main concern is how this approach is going to be implemented and tested experimentally.

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

Reviewer 1:
The reviewer remarked that this project aims to increase the performance of thermal management systems, allowing further gains in power density.

Reviewer 2:
The reviewer said that the project objectives align well with the DOE priorities and future direction.

Reviewer 3:
The reviewer noted that thermal management is one of the critical factors to reach the DOE targets.

Reviewer 4:
The reviewer stated that reducing inverter size and weight helps to enable the EDV marketplace and reduce our dependence on foreign oil.

Reviewer 5:
According to the reviewer, most power electronics are not electrically limited but rather thermally limited and must be run at lower than maximum power to maintain the temperature in an acceptable operating range. Appropriate cooling/thermal management is, therefore, one of the most critical aspects to achieving the high 100 kW/l power density targets for 2025. The reviewer commented that this project uses innovative modifications of proven techniques to facilitate the development of electronics that can meet these aggressive targets.

Reviewer 6:
In theory, the reviewer stated that this project supports the DOE objectives. However, these cooling techniques present many challenges to meeting the objectives. Added mass, cost, and thermal system complexity are in direct opposition to meeting some of the DOE objectives.

Reviewer 7:
The reviewer indicated that the project clearly is relevant to DOE objectives as improved cooling will be critical; however, the approach as presented is weak.

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

Reviewer 1:
The reviewer reported that the resources seem to be adequate to complete the project.

Reviewer 2:
It looked to the reviewer that the resources are currently sufficient considering the ambitious future work proposal.

Reviewer 3:
The reviewer said that resources are sufficient to accomplish the current scope of work, especially if outside participants step up their level of support.

Reviewer 4:
The reviewer noted that the resources appear to be sufficient.

Reviewer 5:
Even though the project has received the full funding, which seems to be sufficient, the reviewer commented that the authors did not presentation any cost assessment.

Reviewer 6:
The reviewer found the resources to be sufficient, but the other industry contacts are vague.

Reviewer 7:
The reviewer had stated previously that $493,000 in FY 2017 and a total budget of $968,000 seem very high for what the author presented.

Presentation Number: elt079
Presentation Title: Advanced Multiphysics Integration Technologies and Designs
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 thought that the approach is sound.

Reviewer 2:
The reviewer said that the work is divided into four areas: two materials/manufacturing and two electrical design. Research is focused on key areas that address important technical barriers, such as new substrates that provide adequate thermal management with better reliability and novel, low-profile, high-current density interconnections with reduced parasitic inductance that also reduce module size and enhance reliability. The reviewer stated that electrical research also hits key challenges, such as minimizing auxiliary and passive components, limiting parasitics, and maximizing efficiency through improved gate-driver design. Each of these projects is valuable in and of itself; however, it is not clear how these four disparate subprojects tie together into a bigger whole.

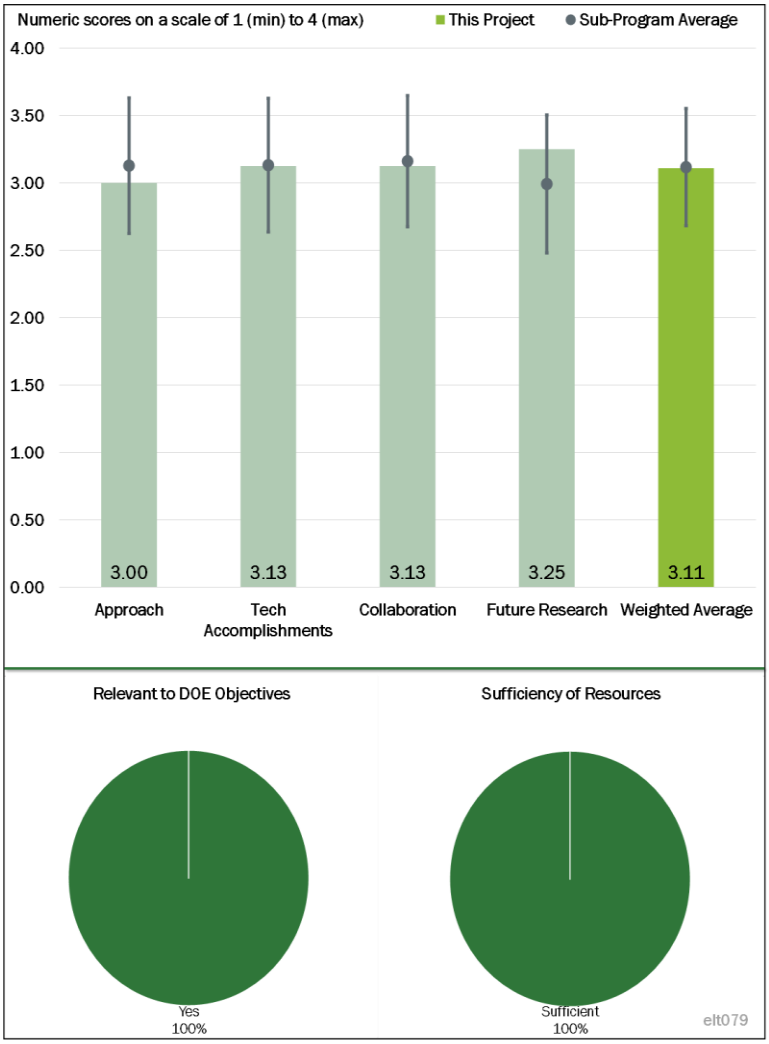

Figure 4-9 - Presentation Number: elt079 Presentation Title: Advanced Multiphysics Integration Technologies and Designs Principal Investigator: Emre Gurpinar (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer brought up that quilt packaging appears to be a promising method of increasing the density of control and gate-driver circuitry. Additionally, if the gate driver can be connected to the power devices with such a short connection, the devices can switch faster and with less oscillation, leading to reduced losses. The reviewer stated that amplitude modulation of the control signal is a proven method of decreasing the isolation transformer capacitance. Combining the control and power isolation onto the same transformer could be quite challenging.

Reviewer 4:
The reviewer found the technical barriers identified to be valid, though the degree to which they are addressed varies. Substrates with improved heat extraction and an insulated metal substrate (IMS) with thermal pyrolytic

graphite (TPG) insert were described by this reviewer as being addressed to a high degree. Interconnects using conductive metal "nodules" on the sides of the chips was described by this reviewer as being addressed to a low degree for high-current power path. Further, inductive coupler was described by this reviewer as being addressed to a medium degree, and the isolated DC/DC converter was being addressed to a low degree.

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

Reviewer 1:
According to the reviewer, the team has made good progress on evaluating packaging technologies and designing the gate driver.

Reviewer 2:
The reviewer stated that significant technical accomplishments have been achieved in the first year of this program, and it is on track to deliver its milestones on time as per the timeline and milestone chart. The team selected and evaluated substrate materials. The reviewer saw that the interconnects have been tested for high-current capacity. The team evaluated several potential gate driver designs.

Reviewer 3:
The reviewer commented that progress is acceptable in accordance with the project plan.

Reviewer 4:
The reviewer recommended that the project team focus on the highest value concepts with regards to the IMS with TPG insert and maybe the chip-to-chip connections. Gate-drive signal isolation and power supply are adequately addressed in other institutions and industry.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented that strong collaborations have been evinced through the substantive involvement of the external partners. Momentive working with Berquist/Henkel has supplied the thermal pyrolytic graphite insulated metal substrate along with thermal conductivity and reliability data. Indiana Integrated Circuits performed the current carrying capability study of the quilt packaging interconnections. NREL provided the thermal modeling. The reviewer remarked that this level of interactions shows excellent team coordination.

Reviewer 2:
The reviewer stated that collaboration appears good.

Reviewer 3:
According to the reviewer, the team is working with several organizations for packaging technologies and with NREL for thermal management research.

Reviewer 4:
The reviewer noted that collaboration and coordination across the team is good and the team is well-formed.

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 pronounced the proposed future work is sound and in alignment with the objectives.

Reviewer 2:
According to the reviewer, the proposed future work is in keeping with moving the program forward and addressing key challenges and risks, such as proper selection of substrate and voltage standoff studies for the interconnections. Future research provides go/no-go decision points at appropriate junctures. The reviewer stated that it would be good for the goal of this future research to produce an actual prototype that included all of these four elements in a single converter.

Reviewer 3:
The reviewer indicated that the team has a good plan in place.

Reviewer 4:
The reviewer recommended the team focus on highest value concepts, with regards to the IMS with TPG insert and that may be the chip-to-chip connections. Gate-drive signal isolation and power supply are adequately addressed in other institutions and industry.

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

Reviewer 1:
The reviewer opined that this project can lead to increased power density and better control over power devices.

Reviewer 2:
The reviewer thought that the project supports the DOE objectives as the project attempts to develop power-module technologies to improve the SiC power module and ancillary components.

Reviewer 3:
Yes, the reviewer said, this project supports the overall DOE objectives of reduced cost, size, weight, and increased power density. Each of the elements of this program is moving towards creating converters with one or more of the following improved characteristics: higher power density, lower parasitics, higher efficiency, faster switching, and higher reliability,

Reviewer 4:
The reviewer's response was that there is relevance to varying degrees: Substrates with improved heat extraction, and IMS with TPG insert to a high degree; interconnects using conductive metal "nodules" on the sides of the chips to a low degree for a high-current power path; inductive coupler to a medium degree; and isolated DC-DC converter to a low degree.

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

Reviewer 1:
It seemed to the reviewer that the resources are adequate to complete this project.

Reviewer 2:
According to the reviewer, resources are sufficient, especially given the level of external cooperation.

Reviewer 3:
The reviewer stated that the project appears to have sufficient resources.

Reviewer 4:
The reviewer recommended a close look at focusing resources on those technologies that have shown the highest potential in year 1.

Presentation Number: elt080
Presentation Title: Performance and Reliability of Bonded Interfaces for High-Temperature Packaging
Principal Investigator: Paul Paret (National Renewable Energy Laboratory)

Presenter
Paul Paret, 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.

Reviewer 1:
The reviewer stated that the approach is excellent; however, the round double-lap test samples are not representative of what is used in industry. Dies are square or rectangular, not round so the die attach should be square or rectangular. Perhaps adding square or rectangular double-lap samples with the round samples would be more representative. The reviewer asked that the graphs of shear-test results have a line drawn showing what is considered acceptable.

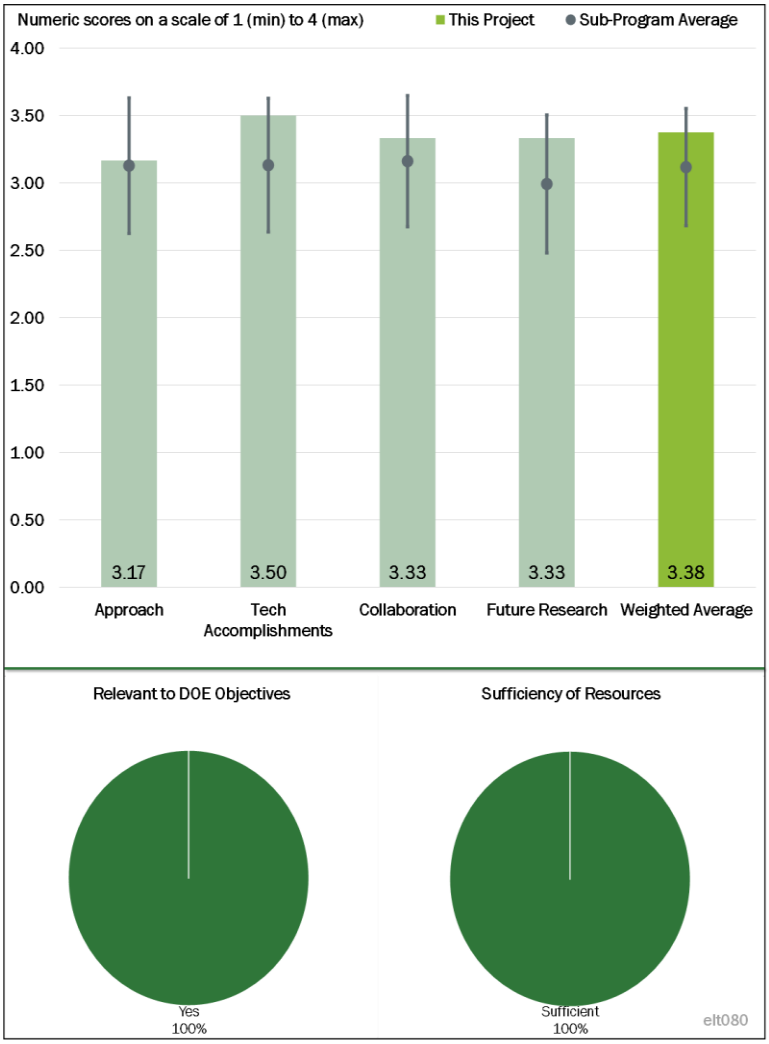

Figure 4-10 - Presentation Number: elt080 Presentation Title: Performance and Reliability of Bonded Interfaces for High-Temperature Packaging Principal Investigator: Paul Paret (National Renewable Energy Laboratory)

Reviewer 2:
The reviewer commented that putting together models to be developed and testing hardware are essential and good. According to the reviewer, validity in applying the J-integral as one of the modeling approaches to this particular purpose needs explanation. The reviewer stated that it would have been nice to explain how the results for the circular-shaped test samples can be correlated with the square-/rectangular-shaped test samples because the square-/rectangular-shape is practically dominated in the actual application field.

Reviewer 3:
The reviewer wanted to know what the technical approach is to achieve the pressure-less sintering.

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 test and modeling results to be good. The thought process to determine the sintering process profile (temperature, pressure, and time) was not quite clear, and the reviewer asked for an explanation.

Reviewer 2:
The reviewer pronounced the approach of build and test, predict reliability, and create a model to be perfect. While this is still a work in progress, it is well done.

Reviewer 3:
This reviewer stated not applicable.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The project team appears to be working well together, according to the reviewer.

Reviewer 2:
The reviewer noted that the collaboration with Virginia Tech and ORNL is good. The reviewer asked for more clarity about "Private industries in power electronics" on Slide 16. The reviewer wanted to know who those private industries are and what they are contributing to.

Reviewer 3:
No response entered.

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

Reviewer 1:
According to the reviewer, the project team is following the approach of build and test, determine reliability, and create model; the team is focused.

Reviewer 2:
The reviewer asked for a description of a plan to verify the developed lifetime prediction model. The reviewer said that it is good that the future proposal includes other high-temperature bonded interface alloys, such as copper-aluminum and copper-tin.

Reviewer 3:
The reviewer wanted to know how to enable the pressureless sintering to achieve the performance similar to regular high-pressure sintering. The reviewer wanted to know what the criteria and projected performance goals are for the success of the project.

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

Reviewer 1:
The reviewer stated that new reliability questions need answering for a full utilization of new wide bandgap power devices with cost-effective packaging. Hence, the reviewer said that this project is quite relevant.

Reviewer 2:
The reviewer remarked that improving reliability of the power electronics is very important (refer to the Prius 2014 inverter issues as a reference), thus allowing EDVs to last longer while reducing costs and lowering our dependence on foreign oil.

Reviewer 3:
This reviewer stated not applicable.

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

Reviewer 1:
It looked to the reviewer that the resources are currently sufficient considering the proposed future research.

Reviewer 2:
The reviewer commented that the resources are sufficient and the team is qualified.

Reviewer 3:
This reviewer stated not applicable.

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 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:
According to the reviewer, there is a satisfactory approach to collecting data and establishing modeling and analysis. The reviewer was interested in seeing the gaps and potential concerns with the supply chain.

Reviewer 2:
The reviewer thought that the approach could have benefited from targeting the ability to offer higher fidelity in the data. For example, the class of commercial vehicles is very wide, with varying power and energy requirements (energy storage, motor sizing, etc.) and duty cycles (long haul, urban duty cycle); in order to truly assess supplier capability and readiness, one needs to understand what range of products the project team can supply or have supplied (motors/batteries sized for 15,000 pounds gross vehicle weight [GVW] for a hybrid vehicle or 30,000 pounds GVW for an EV). When the reviewer asked a follow-up question about whether or not these distinctions would be made to truly understand supplier status, the reviewer was unsure whether this would be available or if the presenter comprehended the importance of these data.

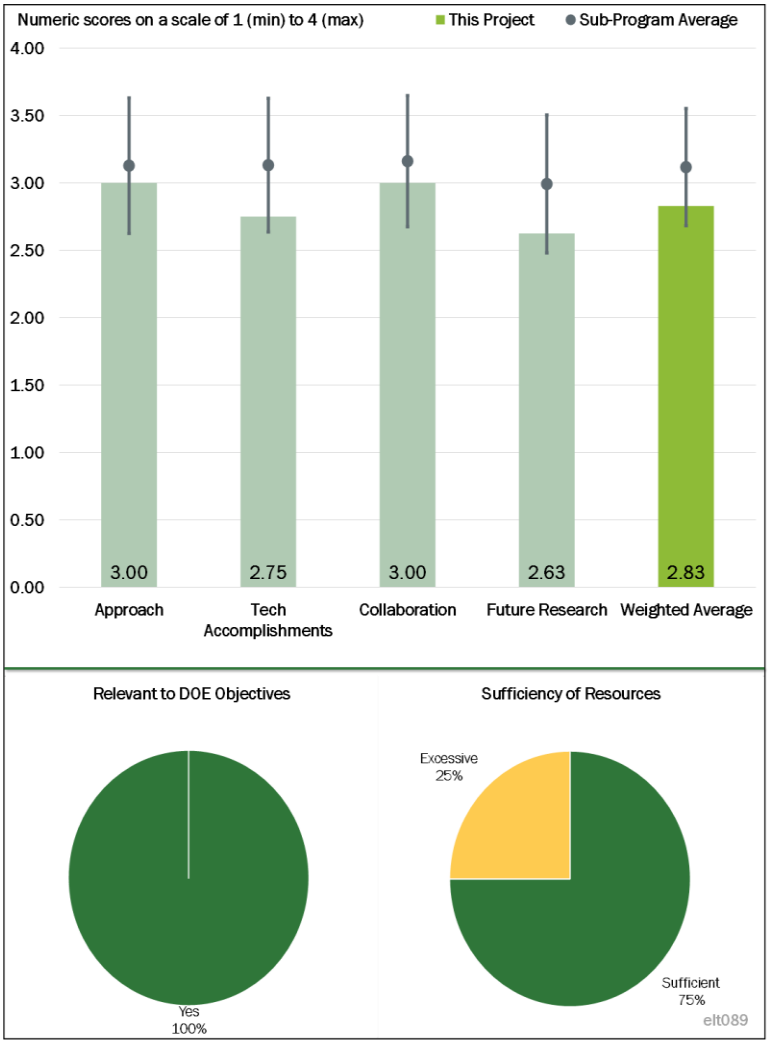

Figure 4-11 - Presentation Number: elt089 Presentation Title: Assessing the North American Supply Chain for Traction Drive Inverters, Motors, and Batteries for Class 3-8 Hybrid Electric and Plug-In Electric Commercial Vehicles Principal Investigator: Chris Whaling (Synthesis Partners)

Reviewer 3:
It was not clear to the reviewer why an analysis of the quantity of electric trucks presently on the road is necessary. The reviewer wondered if that information could be gathered from the appropriate OEM's and asked why the analysis could not be based on a future population of vehicles. One of the goals is to establish and understand gaps in the supply chain. Because OEM, Tier 1, and Tier 2 companies are involved with Class 3 through Class 8 manufacturers who deal with various and different supply chain issues, this project objective seems overly complex to identify with the current work plan.

Reviewer 4:

The reviewer commented that the focus of this project is to identify the gaps, constraints, and bottlenecks in the North American supply chain for traction-drive electrification components (inverters, motors, and batteries) for hybrid electric and plug-in electric commercial vehicles (Class 3-8). The reviewer noted that a number of specific barriers have been identified, including accurate information about Class 3-8 electric commercial vehicles and their supply chains and actionable intelligence on research and development (R&D) gaps that affect autonomous vehicles and Class 3-8 power electronics, batteries, and motors in North America. Other barriers identified include time to process and analyze large amounts of heterogeneous data, accessibility of primary sources both in-person and electronically, navigation to highest value data via source confidentiality agreements, and opportunities to drill-down with subject matter experts (SMEs) on specific Class 3-8 electric commercial vehicle (ECV) R&D gaps.

The reviewer found the Synthesis Partners approach to be logical, well designed, and feasible by addressing many (but not all) of these barriers. The approaches comprise identifying appropriate customer (VTO) questions to be answered, data collection from primary (direct person-to-person discussions) and secondary (research) sources, modeling of quantitative and qualitative data, analysis with gap identification, and a final report with findings and next steps. The reviewer remarked that the approach seems to have cast a relatively broad net including personal communications (direct and email) and electronic sources.

Two questions existed though in the reviewer's mind: It is not clear to the reviewer how the approach specifically addresses time to process and analyze large amounts of heterogeneous data and how to navigate to the highest value data via source confidentiality agreements. Additionally, it is not really clear to the reviewer what modeling of quantitative and qualitative data entails and how this will be of overall benefit.

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 solid technical progress has been made on this project and it seems basically on schedule. This includes completing the report "R&D Gap and Trend Analysis for Autonomous and Connected Vehicles; On Connectivity, Sensors and Sensor Systems (November 2017); 340+ individuals within 220 organizations contacted to elicit information with regards to the North American (NA) supply chain for medium-duty (MD) and heavy-duty (HD) vehicles and associated power electronics, motors, and batteries; production of initial, detailed Class 3-8 component supplier datasets; and sharing of datasets with NREL and ORNL for review and comment. More than 10 initial gaps have been identified in the Class 3-8 North American supply chain.

A question that exists in the reviewer's mind is whether analyses will attempt to look into the future based on what is found in the present state. In other words, the reviewer wanted to know if this project will make any attempt to prognosticate the future for the NA supply chain for inverters, motors, and batteries for commercial HEVs and PHEVs.

Reviewer 2:

It seemed to the reviewer there has been an effort to collect data from the industry, and so the groundwork has been laid to achieve the project goals. For this presentation in June, the reviewer stated that it would have been better to have seen the data analysis further along, given that there are 3 months until the end of the project. Many of the slides were marked as of "April" where it would have been better to see current data. For example, the statement on Slide 14, "Allison H 3000 product on scheduled to begin in Q4 2013," gave the reviewer concern that the data will be the surface level. In the example given, verification of this can be obtained through SEC filings with the company as well as a lot of other data. The reviewer expressed concern that the data may not go deep enough to truly achieve project objectives, or the PI does not completely understand the significance.

Reviewer 3:
The PI did not make the presentation, according to the reviewer; however, it appears that specific supply chains are not identified, although a large collection of suppliers have been contacted. The reviewer did not see how the project collected those data in an objective manner. Furthermore, the reviewer wanted to know the definition of a gap and whether it is the lack of project, a cost that is too high, or something else.

Reviewer 4:
The reviewer pointed out that the presenter was not able to answer specific technical questions when asked.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The overall collaboration and coordination for this project seems strong according to the reviewer. The project has indicated collaborations with a number of entities including: OEMs and Tier 1-4 suppliers, R&D organizations, universities, national laboratories (NREL and ORNL), the U.S. DRIVE Electrical and Electronics Technical Team (EETT), and other VTO stakeholders. The reviewer opined that the distribution of primary sources exhibits a strong mix including senior and mid-level executives, universities, research laboratories, non-profits, and government.

Reviewer 2:
The reviewer believed there was good coordination to be able to go out and actively seek data from OEMs, which can be hard to gather. It is hard to assess at this point whether the best-quality contacts were attained to get all the data needed.

Reviewer 3:
The reviewer believed that a collaboration with a university business school would provide a benefit to the project.

Reviewer 4:
The reviewer stated that the company was able to obtain current supply-base information, but did not provide a forecast or timeline of future supply capabilities.

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

Reviewer 1:
The reviewer responded that the next step is planned to be completed in September and is logical and on time.

Reviewer 2:
The reviewer found the approach to analyze the data to be good. The reviewer had expected an outlook into the future for suppliers' capabilities and a technology roadmap.

Reviewer 3:
This is a 1-year project scheduled to end in September 2018 and has not really identified proposed future work. However, the reviewer asked about any value to comparing the final results of this study to any similar prior studies by other organizations. This may help establish some historical trend lines and build the knowledge base to lay a foundation for future prognostication.

Reviewer 4:
The reviewer stated that it was somewhat unclear about what remains to be accomplished and what, if anything, would be proposed for future work.

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

Reviewer 1:
The reviewer mentioned that the U.S. DRIVE Partnership Goal 1 is to "Enable reliable hybrid electric, plug-in hybrid and range-extended electric and battery electric vehicles with performance, safety, and cost comparable to or better than advanced conventional technologies." According to the reviewer, a robust and secure North American supply chain for inverters, motors, and batteries is essential to achieve this goal.

Reviewer 2:
The reviewer said yes. The reviewer believed that understanding the supplier capability is important to understanding their capability to develop and apply new technology. The reviewer also believed the project could have benefited from further scoping to make sure the assessment provided data on the supplier capability in terms of HEV or EV (power and energy capability for the products they have).

Reviewer 3:
The reviewer noted that this project absolutely supports DOE relevance by providing a study of the supply chain of electric HD vehicle systems and components. It might go further by also reviewing costs of the components and systems at a future state.

Reviewer 4:
The reviewer commented that there was important information for planning and capabilities.

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

Reviewer 1:
The reviewer observed that the resources identified for this project ($460,000) should be sufficient for this project and the stated objectives and milestones identified therein.

Reviewer 2:
The reviewer stated that resources and the timeline to finalize seem to be on track.

Reviewer 3:
The reviewer said that resources are sufficient although the reviewer would recommend gaining third-party business analysis support from a university.

Reviewer 4:
The reviewer asserted that $459,918 of total project funding is excessive for the data requested and seen thus far in this project. As outlined in the presentation, the work considered is: 50+ conversations with SMEs plus 500 phone calls plus 1,000 electronic sources reviewed, attendance at APEC 2018, and constructing the database. The project was funded 100% by DOE. If the PI conducting the research has sufficient contacts within the industry already so that the project team can more readily start data population, then the reviewer opined that it would be reasonable to assume that awarding based on that intellectual property would pay for no more than 1 man-year worth of work for these tasks. The reviewer stated that $250,000-$300,000 should be sufficient to pay for this as well as any travel required to meet in person or fill the rest of the gaps in research. The reviewer commented that many potential PIs who have worked in the field (for example, at the OEMs or suppliers mentioned in the presentation) would be able to fill such a role. If the PI does not have sufficient contacts to readily do this research, then it seemed to the reviewer that the cost should be shared because the PI is gaining prestige from making further contacts in the industry and is able to use those contacts for future work. Even if this is the case, then the $459,918 should be shared 50% between the PI and the DOE.

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

Presenter
PR Subrramanian, GE Global Research

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 the approach taken by the team is good. Building a subscale prototype and evaluating its performance will be an important step before building the 55 kW prototype. However, the reviewer could not find the subscale motor specification. The reviewer was curious to know how specification was scaled down. If the team uses specific scaling laws for the two machines, then the reviewer can get more insights into the designs.

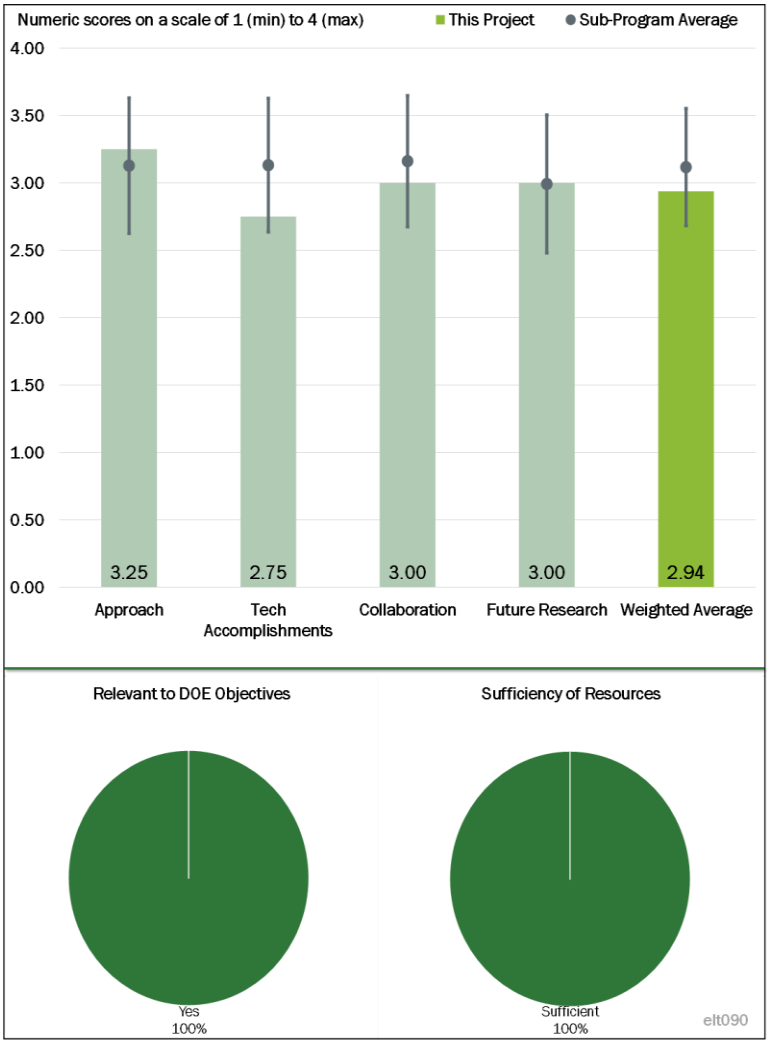

Figure 4-12 - Presentation Number: elt090 Presentation Title: Dual-Phase, Soft Magnetic Laminates for Low-Cost, Non-Reduced Rare-Earth Containing Electrical Machines Principal Investigator: Francis Johnson (GE Global Research)

Reviewer 2:
The reviewer posited that this dual-phase alloy for synchronous reluctance motor looks unique and is an interesting approach, but it was not clear to the reviewer as to the specific motivations to go to a synchronous reluctance motor. The reviewer also suggested that a reasonable route to consider is a non-heavy RE interior permanent magnet (IPM) motor assisted by higher reluctance with this dual-phase alloy. Also, specific challenges and potential roadblock description are expected as key outputs.

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 period is October 2016 to September 2019. With a year left to go, the reviewer thought that one of the major risks that needs to be alleviated is a clear understanding of the tradeoff between mechanical and magnetic properties. According to this reviewer, the tradeoff is at the heart of the success/failure of this project. While there were significant accomplishments, the reviewer wished that this risk had been addressed much earlier in the program period.

Reviewer 2:
The reviewer observed reasonable progress for the motor prototyping. The reviewer asked if there has been any study carried out for long-term mechanical and magnetic characteristics change for this particular dual-phase alloy.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
According to the reviewer, collaboration with a national laboratory and other industry partners is good.

Reviewer 2:
The reviewer said that collaboration exists and it is apparent that the individual team members are working based on their individual commitments.

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 thought that one of the key barriers that needs to be addressed is the tradeoff between the mechanical and the magnetic properties. While building prototypes are perfect to prove the technology, without this key understanding, the project can remain as an industrial research/one-prototype experiment rather than a technology that can be transferred to the automotive world.

Reviewer 2:
The reviewer stated that it is fair to bring up DOE 2020 target. But, the reviewer said that it may also be a good idea to look at the updated U.S. DRIVE EETT roadmap, because the motor power rating is now higher than the targets stated in the Slides 2 and 4. The reviewer accordingly recommends looking into scalability of this work to meet the new electric motor target.

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

Reviewer 1:
The reviewer opined that cost-effective and high power-density electric motor development is one of the keys for EV penetration into the market. New, soft magnetic material technology is a key enabler to realize it.

Reviewer 2:
According to the reviewer, the project, if successful, will be highly relevant for DOE VTO mainly due to the impact it can have in terms of meeting the DOE target comfortably. However, the reviewer's only concern was that the project has not mitigated one of the highest risk elements.

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

Reviewer 1:
The reviewer thought that the team has enough resources to meet the project goal.

Reviewer 2:
It looked to the reviewer that the resources are currently sufficient considering the proposed future research.

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 praised the work done by the team on materials development as outstanding. The sample the team presented in the review meeting gave the reviewer more confidence in hoping that one day this material will be a reality and will be used to make more efficient machines.

Reviewer 2:
The reviewer had several concerns about the project. It was not clear to the reviewer that MnBi magnets can provide a realistic path to replace RE NdFeB magnets while achieving the required performance metrics. Even though the PI mentioned that one of the key enablers is to go to high frequency/speed, the 400 Hertz (Hz) targeted frequency is fairly low compared to current traction motors.

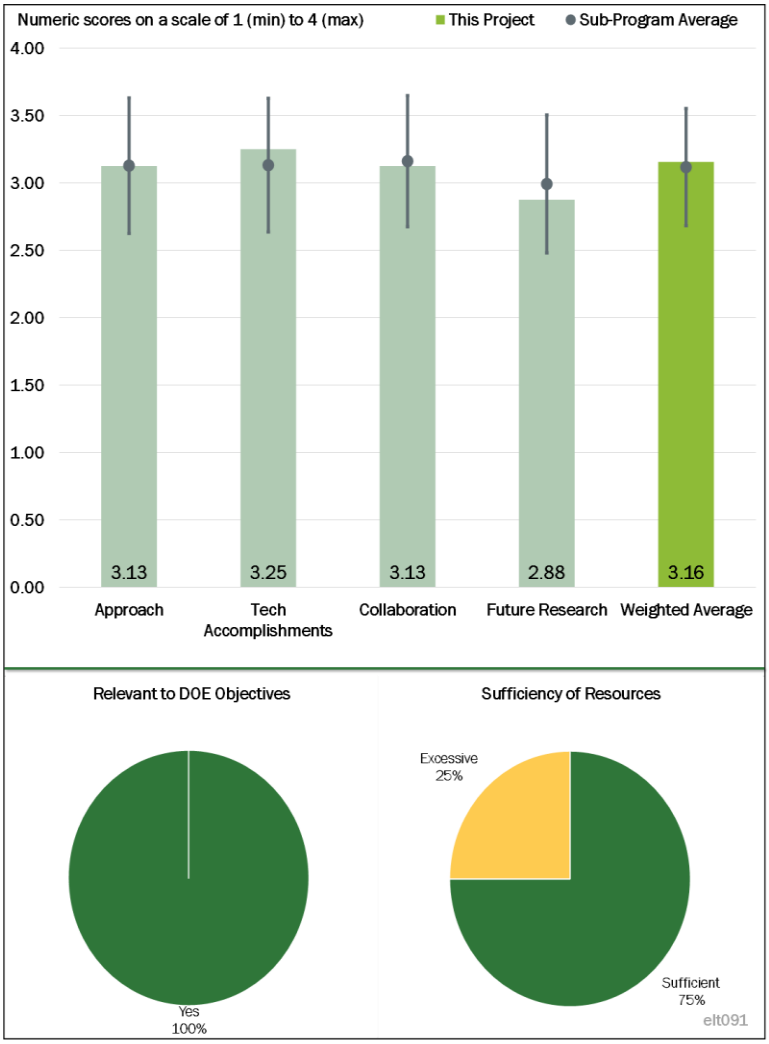

Figure 4-13 - Presentation Number: elt091 Presentation Title: Cost-Effective 6.5% Silicon Steel Laminate for Electric Machines Principal Investigator: Jun Cui (Iowa State University)

The 6.5% silicon steel can lead to higher efficiency, but it was not clear to the reviewer how this can enable non-RE designs. Also, this material can be used with RE designs as well. In general, the reviewer stated that the project seems to be pursuing two or three technical areas that do not seem to be tied together and it was not clear how they can end up providing a comprehensive solution for the RE challenge.

Reviewer 3:
The reviewer said that studying MnBi as an alternative PM material candidate is a worthy activity, considering its unique characteristics of coercivity increasing with temperature increase. Cost-effective production process of 6.5% Fe-Si with maintaining its mechanical strength is also worth looking into in order to achieve the electric motor cost target. Also, this reviewer expected a description of specific challenges and potential roadblock as expected as key outputs.

Reviewer 4:
The approach was unique in that the project team planned to develop practical 6.5% SiFe as an enabler to use MnBi magnet materials to make up for the reduced magnetic properties of MnBi with respect to RE materials. The increase in relative permeability of 6.5% SiFe with respect to 3.2% SiFe alone does not seem enough to make up the gap in remanence for the MnBi to RE materials.

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

Reviewer 1:
The reviewer stated that the team has accomplished the targets very well so far. The fabricated rings look impressive.

Reviewer 2:
The reviewer reported that the team is making great progress in terms of producing MnBi with better magnetic properties and 6.5% SiFe with better mechanical properties. The author showed samples during the presentation and progress appears to be very good with respect to the goals.

Reviewer 3:
The reviewer appreciated the incremental increase of saturation magnetization (M_S) and theoretical energy product (BH_{max}). Wheel speed versus mechanical property relation is informative. The reviewer asked what application assumption led to the choice of a 10-kW peak and 6-kW continuous-rated power motor. The reviewer opined that this is a way low power rating for electrified powertrain applications. The reviewer expected a motor scalability study.

Reviewer 4:
The reviewer observed that progress made on addressing the brittleness of the 6.5% silicon steel is good but scalability needs to be proven. It was not clear to the reviewer that the chosen motor specifications or topology (surface PM) is very relevant to the ultimate DOE specifications.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer stated that there was good collaboration between Iowa State University and United Technologies Research Center (UTRC).

Reviewer 2:
According to the reviewer, there is quite a broad and good range of collaboration of national laboratories, universities, and industries.

Reviewer 3:
The reviewer complimented the program has having many reputable partners in their respective areas and the progress of the program is going very well, especially considering the number of partners to coordinate.

Reviewer 4:
To this reviewer, there seemed to be a disconnect between the team at Iowa State and UTRC, who are almost independently working on this project. What is not clear to the reviewer is how UTRC is going to use the materials developed by the Iowa State. Owing to a large number of members in the team, it was difficult for the reviewer to assess how the rest of the team members are contributing to the project. It was not clear in the presentation.

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

Reviewer 1:
The reviewer remarked that the program has planned further improvement in MnBi and 6.5% SiFe, then building a motor with these materials for demonstration. Demonstration of hardware is always the best way to prove the merits of the development efforts.

Reviewer 2:
According to the reviewer, the future proposed research is interesting from the materials development perspective. However, how these materials will be used to improve motor-power density to 5.7 kW/l is not so obvious.

Reviewer 3:
Similar to some previous comments, the reviewer affirmed that it is important that the research team re-visit the approach and confirm that, even if successful, the developed materials will really enable a feasible rare-earth free design. Also, the reviewer stated that it is important to confirm that the motor prototype is really designed based on relevant specifications.

Reviewer 4:
The proposed direction about MnBi and 6.5% Fe-Si is good, according to the reviewer, who asked why a 400Hz PM motor is being proposed. It looked to the reviewer as if an aerospace application is under consideration. Also, the reviewer questioned if it is just a 10-kW power rating. The reviewer encouraged the project team to refer to the DOE U.S. DRIVE EETT roadmap about the motor development expectations and work on a scalability study.

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

Reviewer 1:
The reviewer remarked that the project is highly relevant from the DOE perspective. If successful, the 6.5% Si steel can drastically impact the performance of electric machines.

Reviewer 2:
The reviewer stated that the project is an ambitious project that tries to address significant issues with two materials. Its ultimate goal is to develop RE free motor designs, which is consistent with DOE's vision.

Reviewer 3:
Cost-effective and high power-density electric motor development is one of the keys for EV penetration into the market, according to the reviewer. Both permanent magnet material and soft magnetic material are key enablers to realize it.

Reviewer 4:
It appeared to the reviewer that the 2020 targets could be within reach, which are the goals stated for the program. There will likely be a large gap between 2025 targets and any tested result; however, these were not original goals. The 6.5% materials also have other advantages in terms of efficiency gains due to the lower resistivity of the materials with respect to 3.2% material.

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

Reviewer 1:
It seemed to the reviewer that the team has sufficient resources to complete the project in a timely manner. They have done well so far.

Reviewer 2:
The reviewer stated that resources seem sufficient based on the proposed scope.

Reviewer 3:
It looked to the reviewer that the resources are currently sufficient considering the proposed future research.

Reviewer 4:
The reviewer noted that there are many contributors to this program; may be appropriate due to the scope of the program touching many different areas and disciplines.

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 observed that the approach seems original and unique in both the WFSM with capacitive power coupler and the hybrid excitation synchronous machine (HESM). Both seem to have merit for decreasing cost and the power factor leading to inverter cost savings. The only concern the reviewer had is the split in focus on the two different tracks as well as the development of multiple technologies and motor prototypes. However, all seem appropriate in meeting the stated DOE 2020 targets. The reviewer would have liked to have seen an analysis of complete system cost reduction, including inverter cost reduction due to optimizing power factor (PF).

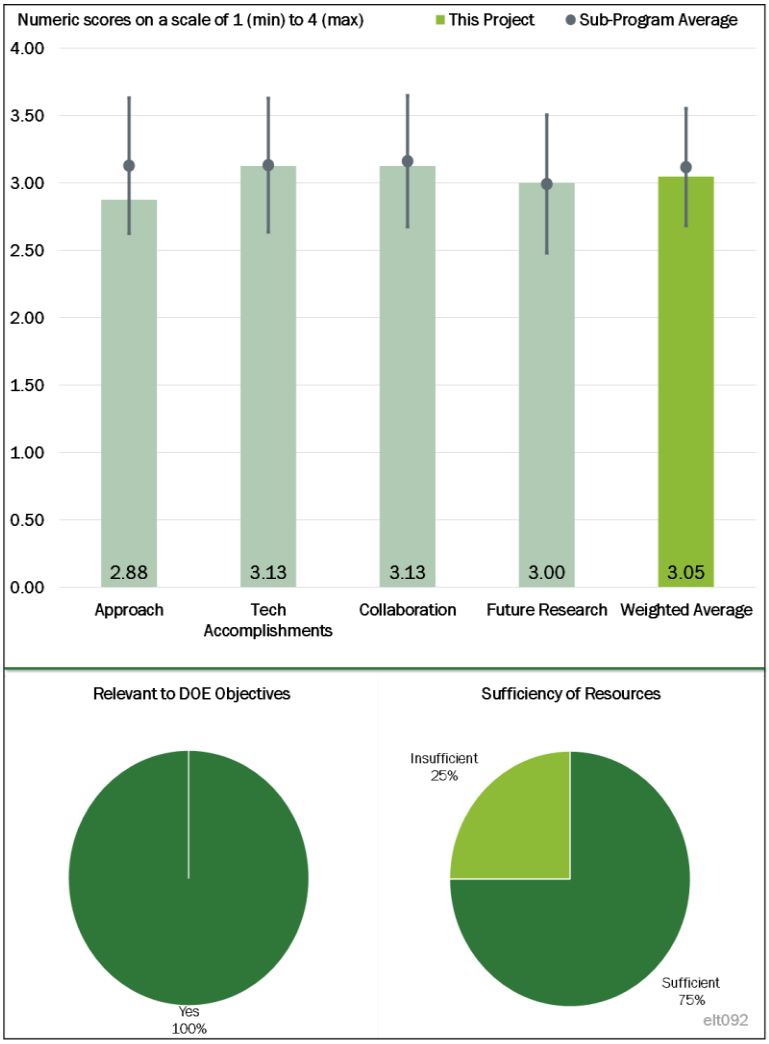

Figure 4-14 - Presentation Number: elt092 Presentation Title: Wound Field and Hybrid Synchronous Machines for Electric Vehicle Traction with Brushless Capacitive Rotor Field Excitation Principal Investigator: Ian Brown (Illinois Institute of Technology)

Reviewer 2:
According to this reviewer, the fundamental concept is interesting. However, there are many moving pieces in this project. It became very difficult for the reviewer to comprehend what affects what as everything is being changed and is a part of the design process. While this approach opens up flexibility, it also introduces a bit of a chaos and randomness. There are way too many prototypes being built and tested, diluting the project's goal. Also, a clear takeaway from each prototype built is also missing. The reviewer was curious to know how this will all contribute to/merge together to meet the project objectives.

Reviewer 3:
The reviewer stressed the authors have to make clear that the project is pursuing two parallel paths, including the wound-field synchronous machine as well as the hybrid wound-field synchronous machine; ultimately, one approach will be down-selected. The reviewer suggested providing a detailed comparison of the proposed

topologies versus a baseline RE IPM design. There are several design pieces proposed according to the reviewer, and it is not easy to quantify the relative impact of each of them. The authors should provide some sort of a quantitative summary/waterfall chart of the impact of the various design factors (capacitive power transfer, pre-pressed windings, control, etc.). The reviewer had a lot of concern about the capacitive power transfer and the very high frequencies required in the megahertz (MHz) range. This can pose serious challenges in a real application, especially in terms of reliability. The proposed hybrid topology is fairly complicated. Similar approaches were previously proposed in literature and did not materialize commercially, mainly because of the level of complication.

Reviewer 4:
The reviewer suggested that hybrid excitation is worth investigating as an alternative candidate of interior permanent magnet synchronous motor (IPMSM) with heavy RE. The approach covers from material utilization (low scrap designs) to control scheme, which is very good. Also, the reviewer stated that the possibility of unity power-factor operation is attractive for drive-inverter. The reviewer said that it would be nice to have a description regarding why the capacitive power transfer has been chosen here, in particular, compared to the magnetic power transfer. It is fair to aim to meet 2020 target (55 kW, etc.), but because the updated target for 2025 has now been released with higher power ratings, the reviewer suggested that it would be a good idea to include a scalability study on this particular 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 found very good progress in various directions in baseline machine prototyping, winding options, electromagnetic and thermal optimization, and a control scheme study.

Reviewer 2:
Technical progress also appears to be on track, according to the reviewer, and is impressive considering the technical challenges. The completion of a prototype motor and separate capacitive power coupler (CPC) has been attained and demonstrated to some degree.

Reviewer 3:
The reviewer pointed out that the project definitely has created many prototypes with many design variations. However, it is not clear how each of these prototypes measures against the performance indicators. The team is attacking machines, controls, brushless power couplers, and capacitive power-transfer inverters. The reviewer mentioned that a clear presentation of how all of these merge together to create the complete drive would be essential to understanding the merit of the project.

Reviewer 4:
The reviewer said that the team has made good progress but there are still several challenges and risks to address.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
It seemed to the reviewer that there is good collaboration between the team members.

Reviewer 2:
There is good collaboration between Illinois Institute of Technology and University of Wisconsin at Madison according to the reviewer.

Reviewer 3:
The reviewer found collaboration to be good among universities and an industry partner.

Reviewer 4:
The reviewer stated that collaboration seemed to be going well considering the progress.

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:
There is a good plan to address several of the remaining challenges according to the reviewer.

Reviewer 2:
The reviewer said that the scope planned for budget period (BP) 2 and BP 3 is comprehensive and aggressive. A lot of value in learning will be produced if the goals can be accomplished. The track record to date indicates that this group can accomplish it.

Reviewer 3:
The reviewer found the step-by-step incremental prototype machine building and testing plan to be good. Electrified powertrain community has a question mark regarding the long-term reliability of the GaN device. Hence, if GaN devices are avoided, the reviewer asked about the limitations and/or trade-offs for an alternative. For example, the reviewer wanted to know how low a frequency can one go if the alternative does not allow going with 2 MHz for capacitive power transfer and a certain assumption of capacitor size.

Reviewer 4:
The reviewer remarked that the proposed research is interesting but there are too many moving pieces without a clear vision of the end objective.

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

Reviewer 1:
The reviewer said that the project is highly relevant to the overall DOE objective. If this research is successful, a new technology can be taken to market that fits the DOE target for the electric vehicles.

Reviewer 2:
The reviewer noted that the project is pursuing RE reduced/free designs, which are in line with the DOE's vision.

Reviewer 3:
The reviewer stated that cost-effective and high power-density electric motor development is one of the keys for EV penetration into the market. The approach taken in this project is worth in-depth investigation as a candidate to take over the role of interior permanent magnet synchronous motor with HREs.

Reviewer 4:
The relevance is a yes, but the reviewer had some major qualifiers. The added expense of the CPC and the associated inverter and peripherals seems significant, and it is difficult to see that it will be offset the main inverter cost savings due to PF improvements. The reviewer stated that machine construction and HESMs do not seem to have major drivers in terms of cost savings. Again, a cost analysis at the system level would be helpful in evaluating these potentially offsetting savings factors.

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

Reviewer 1:
It seemed to the reviewer that the team has sufficient resources to achieve the stated milestones within the period of the project.

Reviewer 2:
Resources are sufficient for the proposed scope.

Reviewer 3:
It looks that the resources are currently sufficient considering the proposed future research.

Reviewer 4:
Though the size of the team among the different collaborators is unknown, it seemed difficult to the reviewer to produce all that is planned. That being said, the progress to date has been significant; therefore, there is no reason to believe the scope cannot be accomplished.

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 said that bringing up multiple options with three variants is good for various electrical machine concepts.

Reviewer 2:
The novelty of the project was not clear to the reviewer. All the machine topologies/variants are well known and have been extensively investigated in the literature.

Reviewer 3:
The approach seemed reasonable to the reviewer relative to the stated goals being 2020 targets and results show power density targets are exceeded. However, most of these architectures appear to have been done before, with the exception of the improved aluminum-copper interface for induction or any novelty to the architectures that were not disclosed.

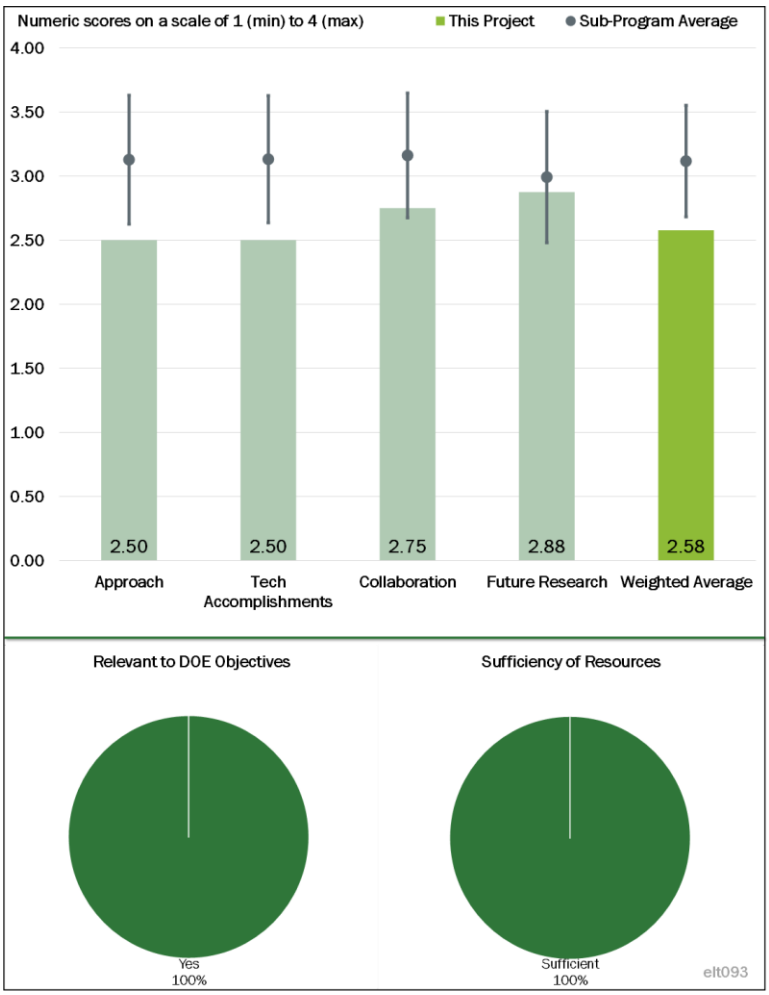

Figure 4-15 - Presentation Number: elt093 Presentation Title: High-Speed Hybrid Reluctance Motor with Anisotropic Materials Principal Investigator: Edwin Chang (General Motors)

Reviewer 4:
The reviewer stated that the project started in October 2016 and is supposed to end in September 2019. With only a year left (almost), the team is claiming to have completed 40%, which is way on the lower side. More interestingly, from the results in Slides 9-11, it seems all the variants meet the DOE targets, which seems a bit unrealistic. Some of the design variants achieve power density way more than the target specification. The reviewer suggested that more detailed analysis and supporting arguments would be better to understand if the results make sense, and if they do, then there needs to be an explanation for why all motor types can attain the spec.

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

Reviewer 1:
The reviewer indicated that materials selection has been accomplished and evaluation of the aluminum-copper interface has been accomplished though it appears fatigue testing is slated for BP 3. It was unclear to the reviewer if the non-HRE material is off the shelf or developed. Most work done so far appears to be analysis, though it also appeared to the reviewer that a thorough analysis and planning phase has been completed.

Reviewer 2:
The reviewer recommended that the key results that were presented need to be evaluated and justified. It seemed to the reviewer that all the probable variants will meet the DOE specification, which is bit surprising. Nonetheless, a more detailed justification would be better to argue why all the design variants match the spec.

Reviewer 3:
It was not clear to the reviewer how the significant increase in specific power and power density is accomplished using fairly traditional machine topologies. There is no information regarding efficiency. There is no information about current density and thermal management of the machines. The condition of 120% of rated current to check demagnetization is typically not a good representation of fault conditions, according to the reviewer. A clear, comprehensive comparison of the proposed designs versus a baseline IPM with RE magnets should be provided.

Reviewer 4:
The reviewer was not quite clear about what non-heavy RE permanent magnet materials are referred to with "grade 1", "grade 2" and "grade 3" on Slide 7. It was unclear what is meant by "Optimized Cu-Al bar" and "Base Cu-Al" bar. Without more technical details regarding those unclear factors, it was very difficult for the reviewer to comment.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer asserted that there was good collaboration between GM and ORNL.

Reviewer 2:
The reviewer found the collaboration between industry and a national laboratory to be good.

Reviewer 3:
ORNL is the only identified collaborator and it was unclear to the reviewer what type of materials testing the laboratory is doing.

Reviewer 4:
The contributions of the individual team members were not very clear to the reviewer. It seemed to the reviewer that there is collaboration, but the presentation seemed to lack detailed support from other team members in highlighting the key results of the tasks 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 stated that building and testing prototypes is critical to prove predicted performance as well as to flush out any manufacturing issues.

Reviewer 2:
The reviewer remarked that future work includes building and testing the motor variants. This is appropriate given that much of the development is at the motor level. Endurance testing is also appropriate as part of the testing due to the nature of the work. The reviewer was not sure why slot fill is also included as it does not seem related to the other development, but nonetheless can improve torque and power density if the design is reiterated.

Reviewer 3:
The reviewer commented that a detailed analysis is required to justify why three design variants match the specification. The remaining challenges were not very clear to the reviewer, who also wanted to know how this future work is going to assist the team in evaluating how to complete the project.

Reviewer 4:
Because the project is completing before 2020, the reviewer said it is fair to set 2020 target, but the updated target looking at 2025 has already been released. According to the reviewer, it would have been nice to have a scalability study with this approach taking this into consideration.

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

Reviewer 1:
The reviewer commented that the project is highly relevant to DOE objectives as the results from this project can provide inputs to selecting a motor that can meet the target.

Reviewer 2:
The reviewer stated that the objective of reducing or eliminating RE material is in line with the DOE objectives.

Reviewer 3:
The reviewer asserted that cost-effective and high-power-density electric motor development is one of the keys for EV penetration into the market.

Reviewer 4:
All development in the project seemed relevant to the reviewer, although some of the approach seems to have been done before.

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

Reviewer 1:
It seemed to the reviewer that the team has sufficient resources going forward.

Reviewer 2:
The reviewer stated that the budget seems sufficient assuming multiple prototypes will be built and tested.

Reviewer 3:
It looked to the reviewer that the resources are currently sufficient considering the proposed future research.

Reviewer 4:
The reviewer commented that GM and ORNL have vast resources more than capable of completing the scope.

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 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 that the overall objective of this project is to develop and demonstrate an advanced PHEV MD to HD work truck with greater than 50% reduction in fuel consumption (compared to a conventional diesel vehicle baseline) with a targeted return on investment (ROI) equal to or less than 5 years. The reviewer listed three phases of the project: the first phase is system design and analysis, the second phase is prototype refinement and verification, and the third phase is vehicle customer deployment and demonstration. According to the reviewer, the primary focus areas are optimization of the powertrain and full vehicle energy use, battery system sourcing and development, and chassis/vehicle/system development and integration.

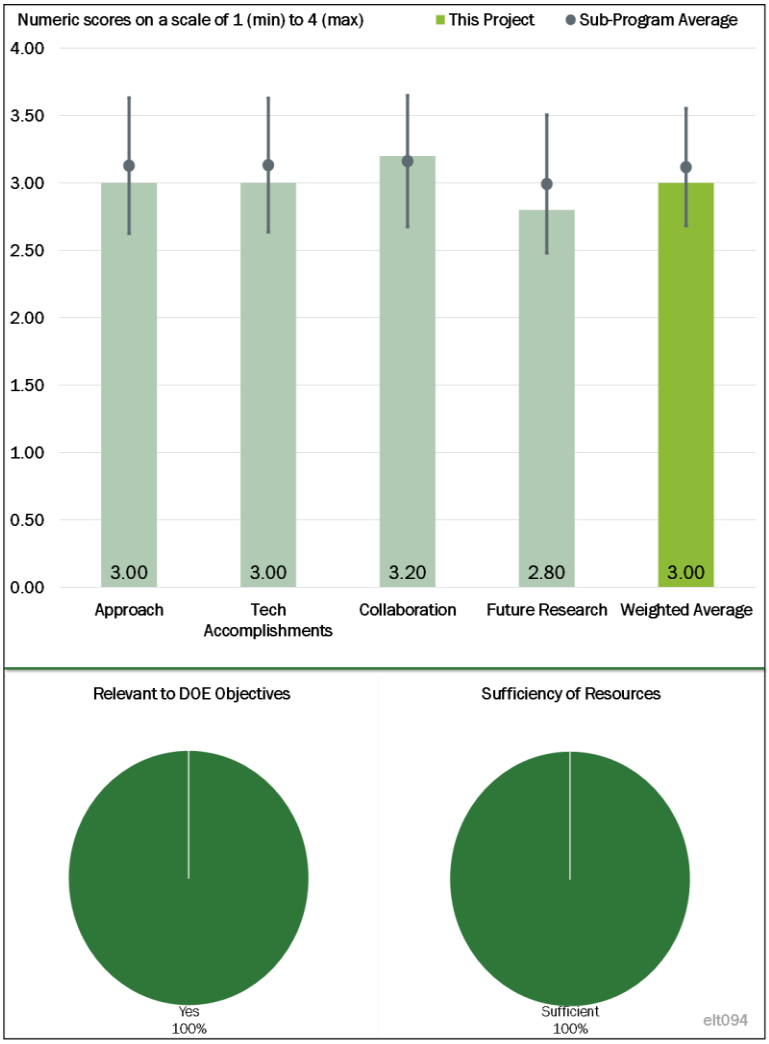

Figure 4-16 - Presentation Number: elt094 Presentation Title: Development and Demonstration of Medium- and Heavy-Duty Plug-In Hybrid Work Trucks Principal Investigator: John Petras (Odyne Systems)

The reviewer noted that Odyne has adopted a very strong approach to this project. The reviewer pointed out that every work truck function is unique and differs day-by-day; therefore, vehicle configuration is dictated by fleet customers. Odyne's approach includes a plug-in hybrid propulsion system and work site idle reduction system, which incorporates a modular design that can be applied to multiple OEM chassis and application platforms using the same base hybrid system. The reviewer found the approach to be minimally intrusive where hybrid power is enabled through the existing power-takeoff (PTO) port. No changes are required to the base powertrain and the powertrain warranty from Allison is retained. The reviewer commented that advantages of this approach include applicability to many OEM work truck models, potentially lower costs due to a larger market, launch assist and regenerative braking (more power, better driving efficiency), battery/electric motor support for jobsite functions, and field recharge via the diesel engine if required with no interruption of jobsite function. The approach is based on an optimized PTO-based hybrid system for a real-world truck, full-day duty cycle. The reviewer said that the team is incorporating a number of cost-reduction elements through functional integration and advancements in lithium-ion batteries, power electronics, and up-

integration into the vehicle. The project will consolidate components, simplify cooling systems, and optimized ancillary components such as brackets.

Overall, the reviewer found the approach to be very solid and logical, addressing many of the key challenges (including modularity/flexibility, consumer acceptance, cost) to incorporating hybrid electric systems into MD- and HD work trucks, which have been very underserved markets.

Reviewer 2:
The reviewer said that the approach used for project timing, architecture, and project planning is feasible to achieve the scope of the project.

Reviewer 3:
The reviewer suggested that the project team consider including air-conditioning (AC) load power consumption for a more realistic overall fuel economy calculation, and testing the impact of cold and hot temperatures on the overall fuel economy calculation and testing.

Reviewer 4:
There appeared to the reviewer a lack of comprehensive vehicle system and component level modeling that was used to derive hardware and control system requirements that could be subsequently cascaded to sub-tier suppliers for design.

Reviewer 5:
The reviewer really liked the idea of using a stock transmission and stock engine. However, the goal of a 50% reduction in fuel consumption when compared to a conventional diesel vehicle baseline is really so ill-defined that it is subjective. The reviewer commented that there is no specification for a baseline with respect to fuel consumption when the baseline transmission and diesel engine have not been defined. The reviewer wanted to know what year, what model, how many cylinders, what horsepower, and what duty cycle.

According to the reviewer, a shortcoming in the approach is the ROI. No needs analysis was done among fleets that deploy work trucks to establish their desired ROI. The reviewer stated that the trucking industry typical desires an ROI of 2-3 years while the project goal was 5 years. If the project goal is not going to be realistic, the reviewer suggested that it should be dropped.

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 progress to be mainly on-track to meet overall project objectives. The team clearly understands the use cases for the utility operators who will be demonstrating this technology.

Reviewer 2:
The reviewer remarked that the propulsion and charging systems are well-defined. The system model, design, and evaluation cycles are clearly selected. The reviewer commented that the lack of a battery supplier and design, if not finalized, is a high risk compared to the other already selected system components (charger, inverter, etc.).

Reviewer 3:
The reviewer said that simulation and dynamometer testing are fine. But, there the project team needs to demonstrate a test plan in cold ambient weather and assess the impact on the battery and overall performance.

Reviewer 4:
The reviewer liked the minimally intrusive hybrid power plus power take-off and modular design applied to an OEM chassis because it is extremely practical and viable. The goal of 50% fuel consumption seems to have

been reached for the stationary work truck use but not for the driving fuel economy. According to the reviewer, a shortcoming is that the battery package was not optimized when it should have been optimized early on.

Reviewer 5:
The reviewer reported that the project has clearly established objectives and is on schedule. The project established a solid list of project milestones for BP 1 and 2. Two go/no-go milestones have been set for June 2018 (prototype design freeze) and May 2019 (prototype vehicle performance validation). The reviewer said that it would have been beneficial if the author provided more detail on the specific criteria for satisfying the go/no-go milestones.

A long list of accomplishments has been presented, including the development and evaluation of both in-motion and stationary drive cycles (including a transient PTO stationary duty cycle for dynamometer testing and vehicle full-day simulation, dynamometer testing and results of a Freightliner-Odyne hybrid work truck chassis over multiple drive and stationary cycles, and simulation correlation (greater than 90% across all drive cycles) with dynamometer results. Other accomplishments include development of a full-year fuel-use model to account for daily variations, spec'ing of battery systems requirements and identification of appropriate suppliers, and new component development/integration and test truck and system layout. The reviewer noted that preliminary results show only modest fuel economy improvements in driving mode, but significant improvements in a stationary model. The author indicated significant emissions benefits. The reviewer mentioned that Odyne believes significant further improvements in driving fuel economy can be achieved through improved calibration, drive optimization techniques, and job site/driving balancing algorithms.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented that the collaboration between team members appears to be well coordinated and ongoing.

Reviewer 2:
The reviewer found the project team to be very strong, incorporating national laboratories, industry at the vehicle and systems levels, a utility, and a municipal entity (South Coast Air Quality Management District [SCAQMD]). The role and function of each team member are clearly defined.

Reviewer 3:
The reviewer commented that the team and collaborations are sufficient and suggested that leveraging some to better understand the utilization of such technology in cold weather environments.

Reviewer 4:
The reviewer stated that roles and responsibilities for each of the involved partner are well-defined except for the charging system.

Reviewer 5:
According to the reviewer, there could have been better collaboration with the actual users, such as fleet owners/operators. There was too much reliance on NREL, which has a lot of theoretical expertise but no hands-on, practical, real-world experience with work trucks. The reviewer said that there should have been a needs analysis done first, followed by a study of business requirements. The reviewer did not see any input from either Sempra or Duke Energy or a fleet owner/operator nor collaboration with an end-user. The reviewer would like to see more emphasis on end-user needs, because the end-user makes or breaks technology deployment. The end-user is critical. The reviewer commented that an interesting end-user to see on this project is a fire engine, such as pumpers, or trucks outfitted with electric arc welding equipment or air compressors.

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 project clearly defines remaining challenges and barriers. The proposed future research is clear, logical, and progressive falling squarely into the framework of the overall project objectives, phases, and milestones. The reviewer commented that targets to demonstrate up to 50% improvement in driving-cycle fuel economy are very aggressive given that early results indicate only modest improvements. Analytical demonstration of a 50% reduction in work-truck fuel use is significantly stronger. The reviewer commented that little specific discussion was provided of alternate means to mitigate risk through alternate development pathways.

Reviewer 2:
The reviewer wanted to see cost targets quantified along with baseline costs and reduced system costs.

Reviewer 3:
The reviewer said that staying on schedule to test the demonstration vehicle is critical and asked that testing in cold weather, under maximum electrical loads, and daily charge/discharge to see the impact on the battery SOC is included.

Reviewer 4:
The reviewer pointed out that the decision to focus the technology demonstration on an upfitting design rather than a more integrated approach will allow for rapid deployment of the technology into the fleet with a high level of confidence, but it precludes the opportunity to optimize the design.

Reviewer 5:
The reviewer stated that the author provided no strategy for demonstration/deployment of the five prototype vehicles in Southern California, and asked what duty cycles, what type of work trucks, or what organization would be deploying the vehicles. The reviewer said that the authors did not provide a strategy for solving the problem of too many vehicles returning to base with excess battery energy remaining. The authors did not provide a strategy for approaching the goal of 50% reduction in driving fuel economy. It would have been helpful for the reviewers to hear these strategies and critique them or suggest improvements.

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

Reviewer 1:
The reviewer said that this project supports the overall DOE objectives of energy reduction because it shows a path to reduced fuel use.

Reviewer 2:
The reviewer responded yes, this project does support DOE objectives to reduce fuel use and emissions from the nation's transportation sector. Historically, analysis and research for MD and HD commercial vehicles have focused on over-the-road and delivery vehicles. The reviewer stated that this project addresses the fuel consumption (and utility and emissions) of work vehicles, which have been notably underserved through the years.

Reviewer 3:
The reviewer found this project to be in line with DOE's clean energy plan, which includes expanding to large-size vehicles.

Reviewer 4:
The reviewer noted improved driving fuel economy and system cost.

Reviewer 5:
According to the reviewer, the issue in answering the question of how relevant this particular project is to the overall DOE objectives is as follows: out of the universe of possible areas for reducing fuel consumption or displacing petroleum consumption in trucks, what proportion is affected by improving the fuel economy of work trucks. The reviewer would argue that work trucks do not occupy a very high proportion, probably in the 10%-20% range.

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 to meet the project objectives.

Reviewer 2:
The reviewer mentioned that total project funding is approximately $7 million (30% DOE) with 70% from industry and the Federally Funded Research and Development Centers (FFRDCs). The project is currently on schedule and the available funding seems sufficient to achieve the project objectives and milestones.

Reviewer 3:
The reviewer said that the identified partners hold the proper experience to ensure a successful project.

Reviewer 4:
The reviewer's comment was that careful monitoring was needed to stay on track.

Reviewer 5:
The reviewer thought that resources are more than sufficient. The reviewer did not think that the analytical modeling and other work by NREL or ORNL are all that relevant, necessary, or even important.

Presentation Number: elt095
Presentation Title: Vehicle-to-Grid Electric School Bus Commercialization Project
Principal Investigator: Andy Moore (Blue Bird Corp.)

Presenter
Michael Boggess, Blue Bird Corp.

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 overall objective for this project is to develop a compelling value proposition for electric school buses based on total cost of ownership including vehicle-to-grid (V2G) and vehicle-to-building services. The project will advance the technical maturity of selected MD, electric drive components to achieve superior energy efficiency and reduced operating costs. According to the reviewer, the underlying philosophy is that a competitive total cost of ownership can be achieved for an electric school bus through optimizing bus capital cost, bus operating cost, and revenue generation from grid integration.

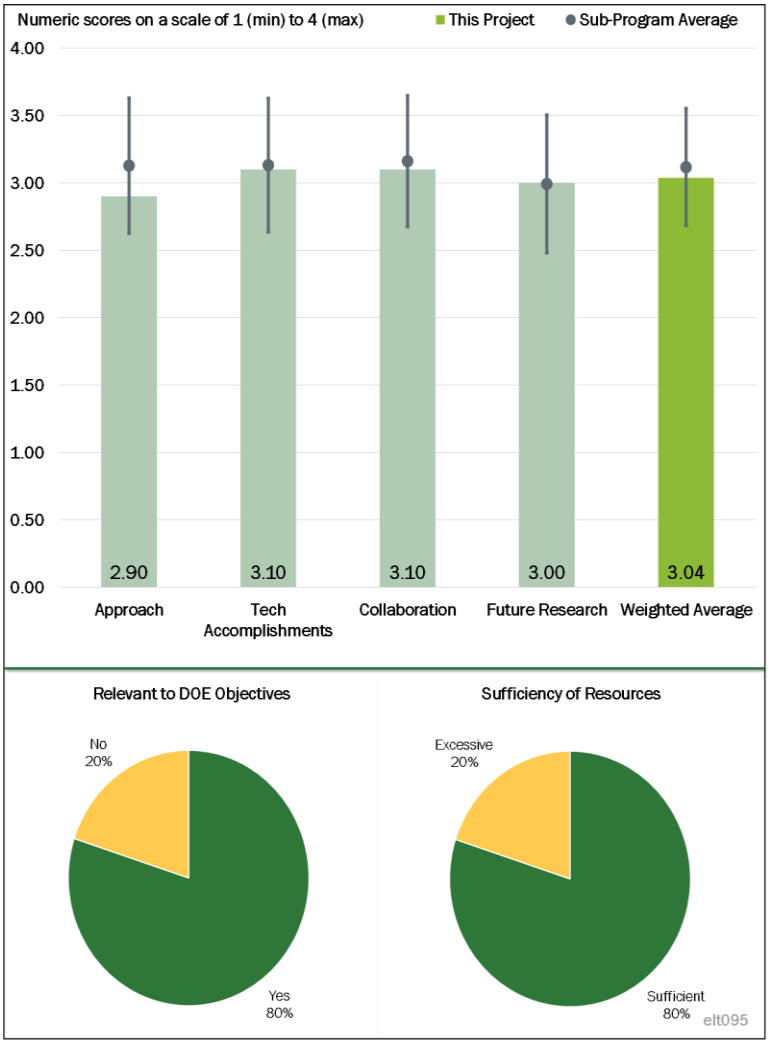

Figure 4-17 - Presentation Number: elt095 Presentation Title: Vehicle-to-Grid Electric School Bus Commercialization Project Principal Investigator: Andy Moore (Blue Bird Corp.)

The reviewer noted that the challenges and barriers are clearly defined including achieving an energy efficiency of 1.1 kilowatt-hour (kWh)/mile (with a 100-mile range per charge target), a fully certified 200 kW bidirectional on-board inverter, implementation of the charging system, demonstration of electric buses both as transportation assets and distributed energy resources, and commercialization. In order to achieve performance, safety, and costs comparable to or better than advanced conventional vehicle technologies, the reviewer stated that the approach targets smart design, advanced telematics, integrated thermal management, as well as high-power charge/discharge capability to capture available vehicle-grid synergies. The project is also looking at localized and spot heating and cooling when it is done while charging as opposed to in transit. The reviewer thought that it is especially compelling that the project emphasizes total-cost-of-ownership parameters (e.g., electricity expense, revenue generation), a production version of the V2G bus with "design for marketability," and development of bus financing tools (e.g., battery leasing scheme).

The reviewer observed that the project is well-designed, logical; it is quite feasible it will achieve its objectives without downplaying the fact that a competitive cost of ownership may not be obtained. The reviewer said that

a comprehensive listing of milestones (with three go/no-go milestones) including start and end dates is provided.

Reviewer 2:
The reviewer stated that the approach used for architecture, type of components selected, simulation, and test plan seems to be good. The critical concern is with the battery source selection, size, and performance.

Reviewer 3:
The reviewer noted that the advantages in charging cost are not clear. Employing a 200 kW on-board inverter over a lighter and more cost efficient, one-way charger is not made clear.

Reviewer 4:
The reviewer said that the overall approach to electrification of school bus fleets is good, but the powertrain architecture selection and the concept of leasing batteries and selling excess power on the grid does not make sense, especially given the high utilization rates. It was unclear to the reviewer how this plan would work to incentivize school districts to capitalize for these systems.

Reviewer 5:
The reviewer commented that there are a number of issues that have to be addressed that are indirectly related to the value proposition for a HD, battery-electric school bus that have nothing to do with the electric drive system or the vehicle-grid integration. The reviewer opined that there is a need to improve the heating/air-conditioning ventilation system efficiency and thermal management system to reduce the demand for electricity. Nothing was mentioned about leveraging the results of the DOE SuperTruck program (in particular, "CoolCab") for heating/cooling the inside of the school bus. The reviewer suggested that there is also a need to reduce the weight of the school bus and its equipment. Again, nothing was mentioned about leveraging the results of the DOE SuperTruck program with respect to weight reduction.

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

Reviewer 1:
Overall, the technical progress seems on track to the plan laid out according to the reviewer.

Reviewer 2:
The reviewer found that the project has demonstrated a number of solid technical accomplishments. Blue Bird has identified direct-drive architecture (single speed) as having the highest energy efficiency across three different duty cycles. The project identified the range of rear axle ratios, meeting standing start on a grade of 20% and a top speed of 65 mph. The team chose the TM4 Suno traction motor based on its low-speed torque performance. The reviewer commented that the bus's thermal management system has been modeled and designed representing the best tradeoff between optimizing thermal energy recovery, cost, and complexity. Blue Bird and Efficient Drivetrains, Inc., have built and benchmarked the first prototype bus, "P1." The reviewer noted that NREL has collected detailed duty-cycle data on buses from the Rialto School District and combined those data with the NREL FleetDNA data to select a representative drive cycle for powertrain development and vehicle efficiency testing. Prototype electric bus P1's energy efficiency has been benchmarked at 1.53 kWh/mile in NREL's REFUEL dynamometer using the NREL duty cycle derived from approximately 1,000 hours of school bus operating data. The "pre-improvement" benchmark will be what subsequent prototypes will be measured against. The reviewer said that the project may be a little behind schedule.

Reviewer 3:
The reviewer said that a cost-benefit analysis is not presented to support the objective of "income-generating grid integration."

Reviewer 4:
The reviewer remarked that the technical accomplishment is limited to analysis and dynamometer testing, based on limited metrics for battery/EV range performance. There is a need to include real-world metrics showing the performance of a school bus under worst-case operation, according to the reviewer.

Reviewer 5:
The reviewer did not have a good feeling that either the electric energy storage system (batteries) or the power electronics (power management system) were optimized. There was no discussion of either system, which are critical to optimizing the kWh/mile fuel economy. The reviewer noted that there was no justification (trade-off studies and comparisons) for whatever system was selected.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer remarked that the project incorporates a multi-disciplinary project team and supportive group of stakeholders. The team is strong and diverse with what appears to be the right balance of industry, a national laboratory, a utility, university, school districts, and state government. The reviewer stated that no notable omissions have been identified.

Reviewer 2:
The reviewer stated that there appears to be sufficient interaction among the team members.

Reviewer 3:
The reviewer said that there was a multi-disciplinary team.

Reviewer 4:
The reviewer commented that coordination among the stakeholders was acceptable.

Reviewer 5:
According to the reviewer, what was lacking was a broader perspective of electric vehicles in general, especially in terms of demonstration/deployment. While SCAQMD was the project partner that dictated the selection of the Rialto Unified School District (Rialto USD) for technology demonstration/deployment, the reviewer saw this selection as myopic because if the project partners had looked at the big picture, they would have seen that Foothill Transit in the adjacent area (San Gabriel Valley), is skeptical about deploying any more electric buses because of their high kWh cost. Foothill Transit is paying more than $0.17 per kWh, and this charge needs to be reduced to almost half in order for the fuel charge to be comparable to diesel or natural gas. The reviewer noted that it would not be good for this project to have a successful demonstration but a failed adoption because of high electric cost by the beneficiary. There is no clear driver (i.e., reason), the reviewer opined, for electric school buses in sparsely populated, suburbanized Rialto as compared to a much more densely populated, urbanized area where parents and citizens are concerned about vehicle emissions.

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 clearly identifies the technology improvements to pursue for the remainder of FY 2018, including thermal management, telematics/drive parameters, high power inverter, and incorporating improvements to EV bus prototypes P1 and P4. The reviewer noted that a very clear go/no-go milestone (M4) is identified at the end of the first quarter of FY 2019 with a target of closing 50% of the gap between the P1 benchmark (1.53 kWh/mile) and the project target of 1.10 kWh/mile. This go/no-go milestone is very notable for its clarity and definition. The reviewer stated that proposed research for

FY 2019 is to assess results of P3 and P4 energy evaluations and identify areas where further technology improvement can achieve big payoffs. This includes refinements to the drivetrain control system, aggressive lightweighting, and reduction in power circuitry energy losses. The reviewer said that the certification phase for the high-power inverter will be initiated. According to the reviewer, the next two quarters are critical to determining the success of the project. Nonetheless, the reviewer opined that it is notable that Blue Bird intends to go to market with an electric school bus that embodies the best possible set of tradeoffs even if there is no guarantee that a competitive total-cost-of-ownership is achieved.

Reviewer 2:
The project tackles all aspect of proposed approach.

Reviewer 3:
The reviewer posited that there needs to be a comprehensive test plan for real-world and worst-case usage.

Reviewer 4:
The reviewer remarked that the future project research does not address key state and federal certification issues or specifically address key cost barriers to adoption.

Reviewer 5:
The reviewer remarked that the PI failed to present any future strategies for achieving the project target of 1.10 kWh/mile from its present status of the P1 benchmark at 1.53 kWh/mile. Considerable, more likely substantial, improvements have to be made to thermal management; heating, ventilation, and air conditioning efficiency; and weight reduction, let alone whether the rechargeable energy storage system and power electronics (power management) system can be or have been optimized.

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

Reviewer 1:
Because this project's objectives are to reduce fuel use, the reviewer stated that it aligns with DOE objectives.

Reviewer 2:
The reviewer pronounced the project to be directly relevant to barriers identified in VTO roadmaps, especially mutually beneficial vehicle-grid integration arrangements that can lead to competitive total-cost-of-ownership and widespread deployment. The reviewer opined that deployment of electric school buses will reduce the nation's petroleum consumption and help achieve better air quality for the nation's school children.

Reviewer 3:
The transportation efficiency improvement and reduced operating cost are relevant, according to the reviewer.

Reviewer 4:
The reviewer said that the project is in line with DOE objectives.

Reviewer 5:
The reviewer commented that the PI already admitted that the PI's company was already commercializing electric school buses that did not meet DOE goals. If these commercialized electric school buses were successful, it is not clear to the reviewer why DOE objectives are important or relevant. Perhaps the DOE objectives are too stringent, and the end-user, that is school districts, does not care about having school buses that meet the DOE objectives. The reviewer thought that DOE would be better off looking at improving the specific components that make up the electric school bus and leveraging the results of the DOE SuperTruck program. The reviewer thought funding a project of this level of commercialization was questionable.

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

Reviewer 1:
Resources appeared to be sufficient to the reviewer to meet overall project tasks.

Reviewer 2:
The reviewer pointed out that this is a large project at roughly $10 million (government and industry total) over 4 years. It is 50% cost-shared. Given the project objectives and scope, the budget seemed appropriate to the reviewer and sufficient to achieve the stated milestones in a timely manner.

Reviewer 3:
The reviewer said that there are multiple organizations with established disciplines and resources

Reviewer 4:
The reviewer noted that barriers and challenges are making the project timing critical.

Reviewer 5:
The reviewer thought that $6.9 million is too much to spend on improving an electric school bus. The budget breakdown for the project was not presented, but perhaps too much funding is going towards modeling, analytical work, and telematics that are not productive or contributing in a cost/beneficial way to improvements in the kWh/mile of the electric school bus.

Presentation Number: elt115
Presentation Title: Zero-Emission Drayage Truck Demonstration (ZECT I)
Principal Investigator: Phil Barroca (SCAQMD)

Presenter
Phil Barroca, SCAQMD

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 stated that the quality of the work in designing, building, and testing a varied set of vehicles is impressive. The reviewer expressed the hope that the analysis work will reach the same standard, so that fleets looking to add new technology vehicles will be able to tell which best fit their needs, are energy efficient, and make economic sense.

Reviewer 2:
In the reviewer's opinion, it was a great approach to a complicated task.

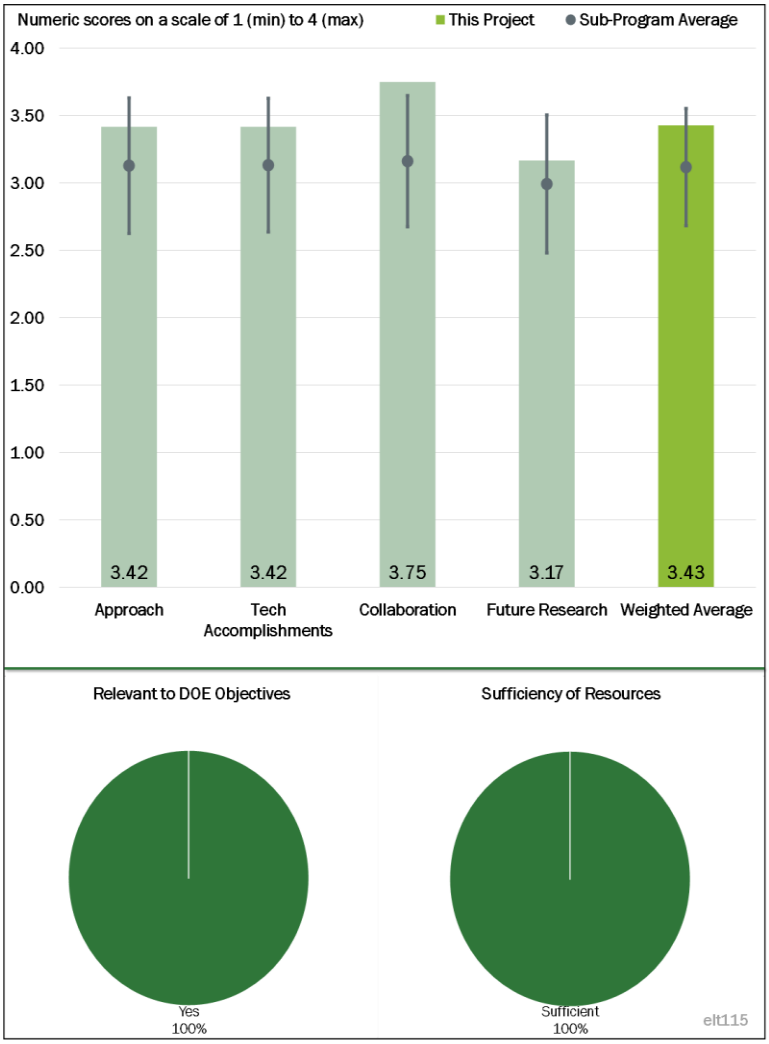

Figure 4-18 - Presentation Number: elt115 Presentation Title: Zero-Emission Drayage Truck Demonstration (ZECT I) Principal Investigator: Phil Barroca (SCAQMD)

Reviewer 3:
The reviewer stated that it is nice to see a project that is building, testing, and comparing multiple solutions on similar routes, as it helps to communicate the best technology for differing duty cycles. The reviewer commented that this is always a key to successful deployment of technical solutions.

Reviewer 4:
The reviewer stated that it was a good plan for highly complex project deliveries, but that the objectives need to be expanded for more definition; i.e., the data collection and analysis objective should explain what type of analysis will be performed on the data collected.

Reviewer 5:
The reviewer noted that there were four vehicle technologies and platforms for cross evaluation.

Reviewer 6:
The reviewer stated that the approach to performing the study did not take advantage of the difference in the number of motors for the battery-electric trucks (BETs), or the difference in parallel versus series hybrid for the plug-in hybrid electric trucks (PHETs). The reviewer further commented that it would have been

interesting to see if single versus dual motors makes a difference in application to duty cycle or type of drayage. Similarly, the reviewer stated that it would have been interesting to see if parallel versus series makes a difference in application to duty cycle or type of drayage. The reviewer stated that it was clear that the difference in the application of BETs versus PHET trucks was range, and relief of range anxiety.

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 not only has the team built the vehicles, there have been several updates and improvements along the way, especially in the battery systems. The reviewer also found that it is impressive that so many miles of operation have been accrued by the trucks.

Reviewer 2:
The reviewer observed good progress towards the plan, especially given some of the vehicle and infrastructure challenges.

Reviewer 3:
The reviewer noted that the project team completed vehicle builds, and most data collection and analysis.

Reviewer 4:
The reviewer commented that there was a need to complete the data collection on new powered units and obtain weight per load.

Reviewer 5:
The reviewer commented that the team persevered through significant issues over this long timeframe. The reviewer further noted that this now 6-year project is dealing with the real-world improvement of battery performance and had to upgrade vehicles with new battery packs, and deal with a partner leaving the program. The reviewer stated that there was a lack of solid performance tracking of the trucks.

Reviewer 6:
The reviewer commented that the results comparing BETs and plug-in hybrid trucks to diesel as a baseline were good; however, it would have been better to see if there was a difference in freeway speed or fuel economy on freeways as a result of the difference in number of motors or parallel versus series mode of hybrid. The reviewer stated that parallel hybrids work best on over-the-road motorcoaches while series hybrids work best in urban city transit buses. The reviewer observed that it would seem to make sense to see if the same applies to trucks—to see if parallel hybrids work better on drayage trucks that travel to farther-out distribution centers while series hybrids work better on drayage trucks that stay within a few miles of the ports.

Nevertheless, the reviewer expressed extreme disappointment that the team collected absolutely no data on the Transpower PHET with the compressed natural gas (CNG) auxiliary power unit. The reviewer noted that it would have been interesting to see how that compares with its LNG analog, and it would have provided a more robust comparison of the two PHETs with the two battery electric trucks (BETs) rather than one PHET with the two BETs.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented that collaboration and coordination amongst parties appears quite strong, and stated that Transpower and US Hybrids view these programs as business development for their companies and understand how to deliver on these types of programs. The reviewer stated that the project was well done.

Reviewer 2:
The reviewer found the project to be successful, considering it was near completion status.

Reviewer 3:
The reviewer commented that it was a great team for the project, and all the bases were covered.

Reviewer 4:
The reviewer stated that, in terms of coordination and cooperation, end-user and fueling infrastructure are important, and expressed the view that, of the two, the most important is the end-user, that is, the fleet owner/operators deploying the prototype trucks, while second is the fueling infrastructure: The reviewer has personally visited the Ports of Los Angeles and Long Beach and is familiar with the natural gas fueling facility—the largest in operation in the United States. Going back to end-users, the reviewer expressed the view that they are excellent in the extent of their cooperation, especially in the area of new alternative fuel technologies.

Reviewer 5:
The reviewer commented that just getting the trucks built required cooperation across the project team, and that operation and updates increased the level required, with no major problems reported.

Reviewer 6:
The reviewer noted that there was good collaboration among the partners to replace the vehicle manufacturer and solve infrastructure fueling issues.

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

Reviewer 1:
The reviewer stated that the research needs to continue with new powered units.

Reviewer 2:
The reviewer expressed a desire to see how the CNG PHET performed if run in electric mode, i.e., not kept at a constant SOC, which might be somewhat of a handicap. The reviewer also indicated a desire to see trucks running closer to their all-electric ranges, as well as some economics. The reviewer remarked that the proposed work covers most other questions that must be addressed.

Reviewer 3:
The reviewer stated that a qualitative list of challenges and needs for the future were listed and discussed.

Reviewer 4:
The reviewer expressed the view that the charging time reduction objective should have considered all charging technologies, such as available and standardized DC charging, which would help substantially with charging time reduction compared to alternating current (AC)/DC charging.

Reviewer 5:
The reviewer commented that it was not clear where future research will be heading on these technologies, but that California and the U.S. federal government seem committed to helping advance zero emission electric vehicles (EVs).

Reviewer 6:
The reviewer stated that there does not seem to be an organized, logical, coherent plan for future research, and that the plan seems to be to try different batteries—upgrades—and see what happens as data are collected.

The reviewer found the demonstration of range to be disappointing; there was no attempt to go more than a daily average of 43.81 miles for the BETs when their listed range was 75-100 miles, while the daily average range was 34.45 miles for the PHET, and its listed range was greater than 250 miles. The reviewer found it ironic that the average daily range for the plug-in hybrid trucks was LESS than that for the BETs, when the listed or expected range of plug-in hybrids is MORE than that for battery-electrics. The reviewer expressed the view that future plans need to do something with demonstrating range and testing range with differences in types of powertrain—battery-electric versus plug-in hybrid electric. The reviewer commented that range anxiety is a critical issue with fleets and drivers

The reviewer suggested planning to see what technology works best in what application or drive cycle, and stated that there needs to be some thought about seeing which type of motor—single or dual—makes a difference in deployment, and which type of hybrid—parallel or series—makes a difference in deployment.

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

Reviewer 1:
The reviewer found that the project supports the overall DOE objectives, due to the wide variety of technology solutions meant to demonstrate emissions reductions.

Reviewer 2:
The reviewer noted that this project does support DOE objectives. The reviewer stated that it should be clear that determining what type of power source, powertrain, number of motors, type of hybrid, and configuration makes the best use of energy in the type of deployment—application and drive cycle—is in line with the overall objective of maximizing energy efficiency and petroleum displacement.

Reviewer 3:
The reviewer stated that the project reduced HD vehicle emissions.

Reviewer 4:
The reviewer commented that the project will reduce fuel usage and emissions.

Reviewer 5:
The reviewer stated that, with the exception of CNG—assumed from biogas—the project will deliver viable trucks that use no petroleum, in keeping with a key DOE goal.

Reviewer 6:
The reviewer commented that there are significant barriers to zero emission trucks, and progress may not be made without DOE funding.

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

Reviewer 1:
The reviewer found the project to be successful, considering it was near completion status.

Reviewer 2:
The reviewer stated that the main expense for this project was building custom trucks, and that the team did a good job of designing a set of vehicles that they could afford to build and test.

Reviewer 3:
The reviewer noted that the program is closing in a few months, and that the resources are in place to finish.

Reviewer 4:

The reviewer stated that retrofitting tractors with different types of energy technologies, especially fuel cell range extenders, is extremely challenging because it is custom-tailored work requiring labor intensive effort.

Reviewer 5:

The reviewer indicated that the project can use more funding and cooperation from the port on load data, such as weight.

Presentation Number: elt116
Presentation Title: Zero-Emission Delivery Vehicle Deployment
Principal Investigator: Andrew DeCandis (Houston-Galveston Area Council)

Presenter
Andrew DeCandis, Houston-Galveston Area Council

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:
According to this reviewer, the project was well-conceived and has helped to address significant technical and logistical questions.

Reviewer 2:
The reviewer commented that the approach was very good in that it was always focused on putting advanced vehicles into the hands of real-world users (UPS), to determine technology readiness. The reviewer further stated that the team correctly identified fleet acceptance (reliability) as a critical factor, and that, ultimately, the project team had to be flexible as it ran into issues with vehicle costs, suppliers, fleet acceptance, and the experimental nature of the vehicles. When issues arose, the team ultimately did adjust to ensure that project needs were met. The reviewer stated that, perhaps above all else, the single most important approach element was the selection of a committed fleet partner.

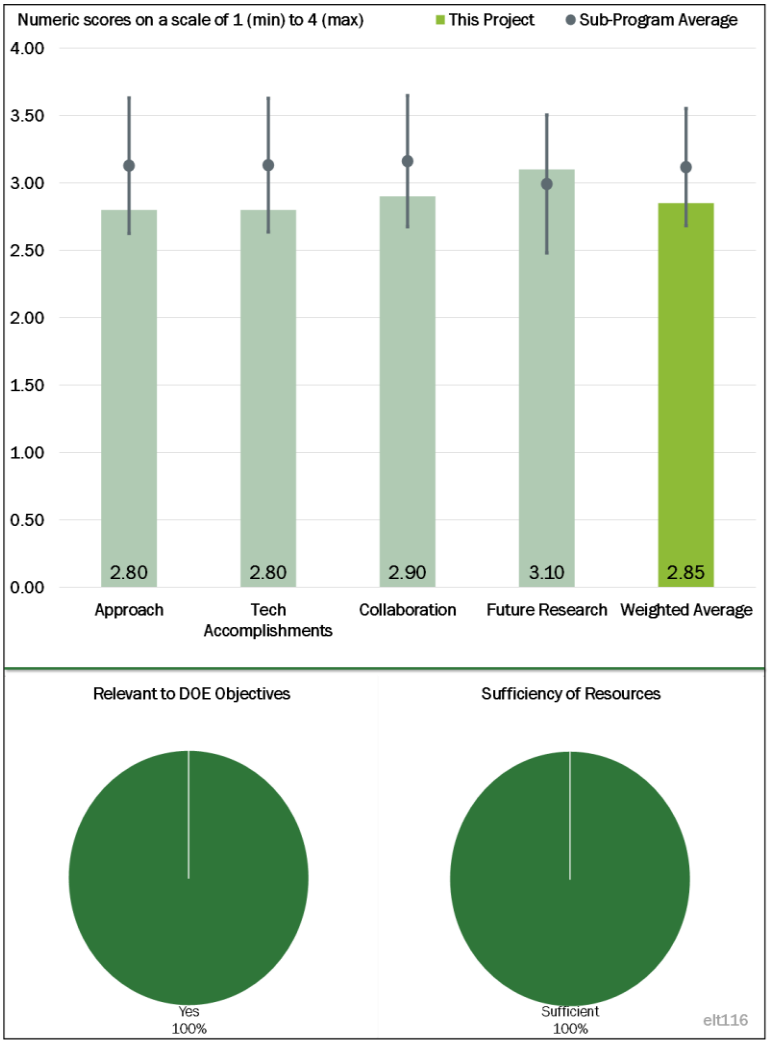

Figure 4-19 - Presentation Number: elt116 Presentation Title: Zero-Emission Delivery Vehicle Deployment Principal Investigator: Andrew DeCandis (Houston-Galveston Area Council)

Reviewer 3:
The reviewer observed that identified barriers included the high cost of low-volume EV trucks, fleet acceptance of the vehicles, and uncertainty in production capabilities and timeline, particularly for experimental vehicles. The reviewer noted that project funding to pay for these vehicles addressed the cost barrier in the short term, but said that it would have been nice to see something on how this project approach helps to address cost barriers in the long term. The reviewer commented that the project's placement of vehicles for use by fleets is a reasonable approach to address the fleet acceptance barrier, but pointed out that, as the presenter acknowledged, having some performance, reliability, or up-time incentives in the contract with the manufacturer would have been an improvement on the approach. The reviewer further stated that, with the benefit of hindsight, the early approach of the project could have been improved through selecting a different

manufacturer partner from the outset, but the ongoing approach to monitoring the performance and utilization of vehicles in the fleets alongside comparable conventional vehicle operation is good.

Reviewer 4:
The reviewer stated that deploying new technology in the real world is important to customer satisfaction during adoption. The reviewer commented that the approach here was strong, and that support for new technology doing real freight movement is generally underappreciated. The reviewer concluded, however, that 36% uptime is not acceptable, even for something this far in the future, to get fleets to want to participate in these programs in the future.

Reviewer 5:
The reviewer stated that the largest issue with this work was the lack of support for the vehicles in case of failures, which were numerous. The reviewer added that, although some miles were accumulated, the decreasing mileage due to component failures could not be addressed, and most regions showed little mileage accumulation. The reviewer commented that there was insufficient planning for vehicle support in the 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 commented that the team overcame a number of issues earlier in the project, but, at the same time, there have been operational issues with both hardware and software, now that the vehicles are in use, resulting in significant down-time. The reviewer observed that Workhorse has been modifying the vehicles, but the units are being used by UPS to deliver packages, and overall utilization to date is 36%, although the trend is heading down. The reviewer commented that some vehicles have reached nearly 98 miles in a day, with an average trip length of 49 miles. The reviewer stated that it should be noted that the EVs do demonstrate significant cost savings—1/3 of the operational cost of diesels—while demonstrating major greenhouse gas reductions.

In this reviewer's opinion, the issues that arose, and the solutions developed, have helped the vehicle manufacturer to improve its product, particularly where hardware selection is concerned. The reviewer commented that, most importantly, despite technical issues with the Workhorse product, UPS has agreed to buy many more to operate in its fleet. The reviewer concluded that the information and experience developed under this project is assumed to have helped UPS build the confidence it needed to make that decision.

Reviewer 2:
The reviewer commented that progress was good, but utilization rates continue to be low, which limits the amount of data.

Reviewer 3:
The reviewer noted that this program is ending, and stated that the low utilization makes for this to be a tough grade, but the trucks did remain in service with many fixes.

Reviewer 4:
The reviewer observed that mileage was collected, but the overall fleet numbers were low. The reviewer noted that the plan was to have utilization near capacity for these vehicles; however, reliability issues with vehicles and chargers greatly reduced utilization to a fraction of what was intended.

Reviewer 5:
The reviewer commented that the vehicles are deployed and operating in the UPS fleets, but it is unfortunate that they have been plagued by reliability problems and have had such low utilization rates. The reviewer stated that, based on this, it would seem that the project has had the opposite of the desired result, which was to build local fleet acceptance and confidence in the new technology. The presenter indicated that UPS is

nonetheless doubling down on EV evaluations in multiple fleet locations and feels that the technology is progressing in the right direction, so the reviewer considered this to be a positive outcome, if these improvements are indeed occurring. The reviewer hoped that the fleets see better reliability going forward. The results indicated that the vehicles are able to satisfy the vehicle range requirements when they are able to operate, and that the energy costs are significantly lower per mile driven than for the conventional version of the vehicles; however, the reviewer found that a clear pathway was not shown for getting the capital and maintenance costs into a competitive range with the incumbent technology.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer observed that the project team appears now to be working closely with Workhorse to resolve issues, and UPS has stood by the project throughout, despite the operational problems. The reviewer expressed the opinion that having a strong user partner like UPS has been critical for this project, and remains critical to ensuring ultimate deployment by industry.

Reviewer 2:
In the reviewer's opinion, the team seemed to work well together.

Reviewer 3:
The reviewer observed that collaboration seems good, but could have been improved, which would have improved utilization.

Reviewer 4:
The reviewer stated that the Center for Transportation and the Environment is leading the data collection for the project, and seems to be working effectively with UPS to collect data on the performance of the vehicles and reporting these data to the prime (HGAC). In the reviewer's opinion, the OEM partner, Workhorse, could be more effective at providing service support to improve up-time for the vehicles in the UPS fleets.

Reviewer 5:
The reviewer stated that insufficient planning for support of the vehicles was apparent; however, this serves as a good educational moment for implementing new technologies into fleet settings.

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

Reviewer 1:
The reviewer expressed the view that this project, and its reporting over the years, has helped EV developers, and developers of EV components, such as batteries, to bring better, more reliable products to the marketplace. The reviewer stated that these sorts of projects help bring to the surface issues related to temperature, weather, driver interactions, dirt and grime, roads, etc., that occur in the real world, and that manufacturers often are not aware of.

Reviewer 2:
The reviewer observed that the project is winding down, with the demonstration to end in November 2018, so there is not that much left to do, but completing the demonstration period and compiling results is important for future potential adopters of the technology, as well as Workhorse itself.

Reviewer 3:
The reviewer noted that continuing the data collection and analysis are the only remaining tasks, but that these are critical to determining the overall conclusions to be drawn for local delivery fleet operators.

Reviewer 4:
In the reviewer's opinion, at this point in the project, focus on continued in-service evaluation of the deployed vehicles and, to the extent possible, maximizing their up-time seems like the correct focus for continued work, and is likely all that is practical with the remaining budget. The reviewer stated that exact numbers were not given, but interpreted the current expenditure level to be indicative of the available project burn rate through the end of the project.

Reviewer 5:
The reviewer commented that it is not clear how the fleet operators are going to work with the vehicle providers to overcome the parts and charging failures to increase reliability and utilization of the vehicles in the fleet.

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

Reviewer 1:
The reviewer noted that the project is focused on deployment of electric trucks to displace petroleum, which is fully in line with DOE objectives.

Reviewer 2:
The reviewer found that this project's objectives explore reduction in fuel use and energy consumption, which is a key DOE objective.

Reviewer 3:
The reviewer stated that early detection of issues not found in laboratories is very helpful.

Reviewer 4:
The reviewer commented that, although there are a number of issues with getting these vehicles to a high utilization rate, some data have been collected to demonstrate the reduction in petroleum use as well as the calculated reduction in carbon dioxide (CO_2) emissions.

Reviewer 5:
The reviewer stated that improving the state of the art for electrified delivery vehicles is relevant for DOE objectives to diversify transportation fuel sources and decrease energy costs for fleets. The reviewer also commented that it is at least mildly disheartening that the current project suggests there is still a pretty long way to go to realize these benefits.

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 funding appears sufficient, and the project is ending soon.

Reviewer 2:
In the reviewer's opinion, the resources being spent currently and over the last couple of years—approximately 1%-2% of the original project budget—seem sufficient for monitoring of the vehicles through the end of the project period of performance.

Reviewer 3:
The reviewer stated that the project resources appear sufficient to complete the project.

Reviewer 4:
The reviewer noted that the program is ending.

Reviewer 5:

The reviewer stated that sufficient resources were provided, and that issues were associated with parts failures.

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

Presenter
Joseph Impullitti, SCAQMD

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 noted that a number of vehicle technologies are being evaluated in demonstrating zero emission drayage utilization, and stated that the variety in designs should yield insight into benefits and issues associated with each technology.

Reviewer 2:
The reviewer commented that this is quite a big project, with $20 million in funds, and that evaluating various technologies in the same drayage application is good. The reviewer saw this project as a simple way to evaluate the technologies.

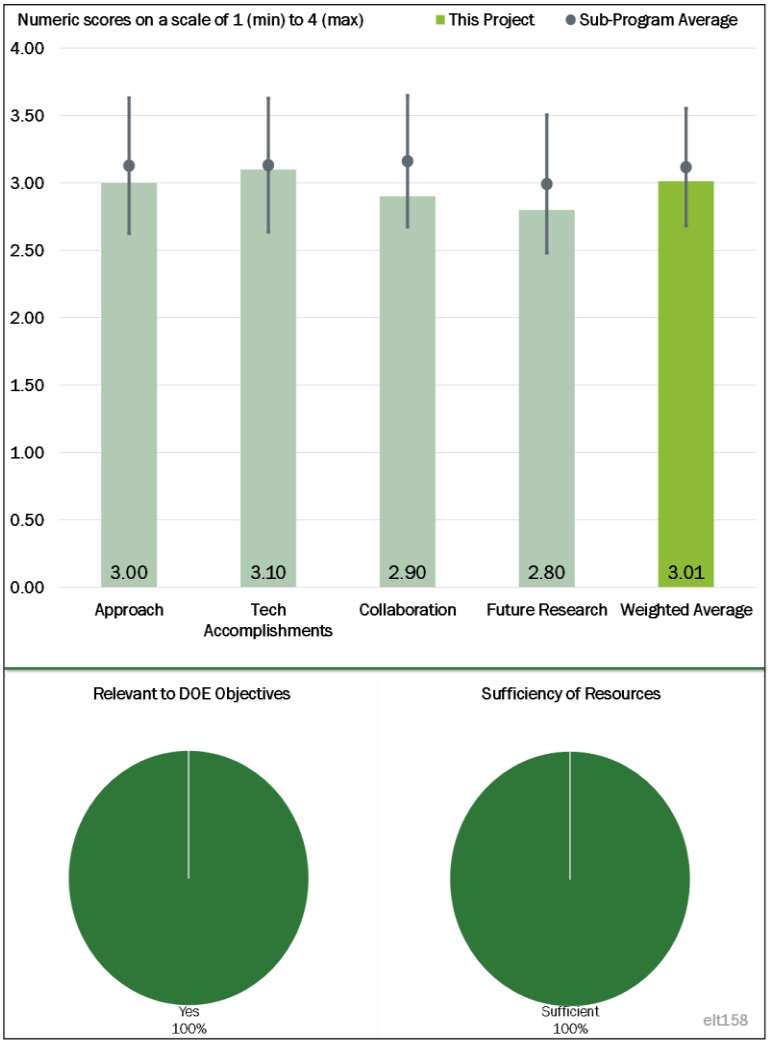

Figure 4-20 - Presentation Number: elt158 Presentation Title: Zero-Emission Cargo Transport II: San Pedro Bay Ports Hybrid & Fuel-Cell Electric Vehicle Project Principal Investigator: Joseph Impullitti (SCAQMD

Reviewer 3:
The reviewer noted that the presentation did not include specific "approach" slides, but that it can be inferred that the approach is to try out a number of different alternative vehicle configurations and evaluate which seem to have the best maturity and promise for reducing emissions and diesel consumption by drayage trucks. The reviewer observed that, over the past year, the approach seems to have focused on efforts by the contractors to complete their design and build work on the vehicles and to conduct their own testing, and in some cases the vehicles have started deployed service at the ports.

Going forward, the reviewer assumed that the approach will shift to evaluating the zero-emission cargo transport (ZECT) vehicles' performance against comparable conventional vehicle performance in drayage operation. In the reviewer's opinion, these steps seem appropriate to achieve the project goals. The presenter stated that a formal total cost of ownership analysis is not part of this project, but that CALSTART is taking a look at that. The reviewer indicated that it would be nice to have that or a similar adoption analysis conducted as part of this specific project, to evaluate not only impacts from different levels of potential vehicle adoption,

which is mentioned at the end of the presentation, but also what might be required to achieve the various penetration levels—such as cost reductions for the advanced vehicle technologies, diesel price levels that would result in a positive total cost of ownership calculation, overcoming any performance limitations relative to conventional drayage vehicles, considering any limitations on the number of use cases where owners would be comfortable replacing conventional trucks with these alternative powertrain options, and/or the need for or impact of emissions regulations near the ports if that would end up being the primary driver for adoption.

Reviewer 4:

The reviewer commented that the goal of building and testing hydrogen fuel cell tractors is laudable, although there were many challenges and also some setbacks. In the reviewer's opinion, there needs to be both applied and basic research and development on the use of hydrogen propulsion for trucks, even though it has been done for transit buses. The reviewer stated that it is not clear why a CNG hybrid tractor was included in this project, for it does not involve fuel cells—as the title of the project would imply—and CNG hybrid technology has already been commercialized. The reviewer cited as an example the CNG hybrid transit buses running on the 16th Street Mall in downtown Denver, Colorado.

Reviewer 5:

The reviewer stated that this work does a good job on the building and demonstration of novel vehicle types, but the reviewer was unconvinced that the choice of vehicles is representative of those that will be most efficient and economical in actual operation. The reviewer stated that it will be very important in the analysis phase to compare the vehicles to each other and to other vehicle types, for different types of routes and usage, and, in particular, it would be useful to compare vehicles that use the available biogas directly with those using hydrogen from biogas.

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 technical accomplishments over the past year of performance included hydrogen fueling infrastructure installation for use by the vehicles. In addition, progress was reported by each of the manufacturers on building and testing the vehicles and certifying them for deployment at the ports. The reviewer noted that in all cases the presenter reported good progress. The reviewer observed that barriers were identified through the course of the hydrogen infrastructure installation, including the preclusion of a permanent hydrogen station installation, but the use of portable hydrogen dispensing appears to be adequate to satisfy the fueling needs of these vehicles.

According to the reviewer, one open question will be whether the hydrogen vehicles' range will be limited by round trip driving distances—if they are in practice limited to only refueling at these portable hydrogen fueling installations—which will place them at a relative disadvantage to conventional vehicles that may travel farther and refuel away from the port. With respect to the vehicle builds and testing, the reviewer commented that nearly all of the vehicle designs appear to be complete, with testing well underway or completed, and the replacement contractor for the fuel cell range extended drayage truck was reported to be making good progress. The reviewer noted that, according to the presenter, manufacturers apply rigorous criteria—BAE/Kenworth was specifically mentioned as requiring five consecutive days of faultless operation in closed course testing—before releasing the advanced technology vehicles into the field. The reviewer commented that this is prudent to minimize the potential for performance problems that would leave the drayage operators with a negative perception of the advanced technology vehicles' capability and reliability.

Reviewer 2:

The reviewer indicated that progress is what would normally be expected on a project of this type involving the fabrication of prototypes, and added that there are many unanticipated challenges and upsets.

Reviewer 3:
The reviewer noted that the objective of completing the vehicles and beginning testing in 2017-2018 has begun and some data are being collected, and added that, although not all of the vehicles were completed, it appears they are due shortly and should begin testing within the timeframe set.

Reviewer 4:
The reviewer commented that it is unfortunate that one of the three players needed to withdraw. The reviewer remarked on the excellent accomplishments, with respect to setting up fueling stations and other infrastructure support for these demonstrations.

Reviewer 5:
The reviewer stated that progress is very good, in spite of glitches like not leaving enough room for the power module. The reviewer commented that perhaps the thermal management issue could also have been foreseen.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commented that strong collaboration is evident, and that the companies understand how this co-funded work is crucial to their startups and adoption opportunities.

Reviewer 2:
The reviewer stated that the degree to which disparate systems are being successfully mated is impressive.

Reviewer 3:
The reviewer commented that there was not a specific collaboration and coordination slide, but clearly multiple contractors are involved in building the trucks; various providers and agencies were involved in getting the portable hydrogen stations in place; and, presumably, the ports and fleet operators are coordinated to operate the vehicles in-service. The reviewer noted that it was not clear how data collection, analysis, and performance reporting will be conducted over the coming year, but expressed hope that this will be well coordinated and will give a good picture of how the vehicles are performing relative to conventional drayage vehicles.

Reviewer 4:
The reviewer observed that the presentation failed to list the end-users who will be testing the prototype hydrogen fuel cell trucks at the Ports of Los Angeles and Long Beach, and expressed hope that TTSI and members of the Harbor Trucking Association are involved, or are at least offered an opportunity to volunteer in testing. The reviewer has found TTSI eager and willing to try new alternative fuel technologies.

Reviewer 5:
The reviewer commented that support across the technical and engineering side of the vehicle development appears to be good and sufficient; however, coordination with the hydrogen supply side—permitting, etc.—remains a barrier.

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

Reviewer 1:
The reviewer commented that the future research that is planned to better detail the business case and commercialization rollout by CALSTART will significantly help long term adoption.

Reviewer 2:
The reviewer stated that it will be very important to do a complete economic analysis for the various truck types, and to compare the results to those for other configurations and operating modes, including ones that use batteries and other more conventional technology combinations. The reviewer commented that, even if the demonstration trucks operate efficiently, they may be much more expensive than other types that are as efficient, or nearly so.

Reviewer 3:
The reviewer stated that future work for the project will evidently include completing the build, testing, and deployment of those vehicles that have yet to do so, along with use, data collection and evaluation of the vehicles in drayage service. The reviewer noted that one of the identified barriers for the proposed technology is fueling infrastructure availability and location. The presentation indicated that the South Coast Air Quality Management District (SCAQMD) is working with others toward permanent fueling stations, but that this will be a challenge. The reviewer indicated that, for this specific project, it seemed the temporary stations should suffice.

The reviewer commented that the presentation identified "System Integration: Safe and efficient deployment of the technology" as another barrier that the project should help to address, through integration and deployment of a variety of different ZECT vehicle designs. With respect to the cost barrier—for fuel cells, batteries and infrastructure—the reviewer found that the project seems likely to have a lesser impact, as the factors that dictate these costs are beyond the scope of what the project can substantively influence. The reviewer noted that the presentation gave a small mention of future commercialization research, but recommended that this be a stronger point of emphasis in the final year of the project, to more rigorously quantify realistic pathways for the technologies to achieve broad commercialization. The reviewer commented on how far those pathways are from present day conditions.

Reviewer 4:
The reviewer observed that the strategic plan for future research and testing, in particular, was not included in the presentation. The reviewer expressed hope that with the different varieties of fuel cell technologies, the future test plan would take advantage of seeing what type of deployment—application and duty cycle—would best fit the battery-dominant trucks—BAE/CTI, Transpower, and Hydrogenics—and the fuel-cell dominant trucks—US Hybrid. The reviewer stated that it is not clear that this would be an apples-to-apples comparison, because the power, torque, range, and other performance specifications may not be the same across all four trucks, and the presentation did not contain one chart showing or comparing all of these features at the same time.

Reviewer 5:
The reviewer found this to be the weakest portion of the presentation. The reviewer observed that a number of interesting and varying technologies will be deployed to address zero-emission requirements; however, there was no clear formulation of how or what data would be collected from the vehicles and how it would be used to best understand the technologies and benefits. The reviewer expressed the view that this work would be improved by a more concerted effort in developing the data acquisition and analysis side once all of the vehicles go into use, and stated that this would be a critical step in relaying information to industry and program partners about the performance of the technologies investigated.

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

Reviewer 1:
The reviewer commented that this project is relevant because it meets the DOE objective of petroleum displacement, and as hydrogen is a clean fuel producing no emissions, it serves national environmental goals as well. The reviewer stated that this research and testing could not, and would not, have been done by the private sector.

Reviewer 2:
In the reviewer's opinion, this project lines up directly with DOE's objective to reduce our dependence on petroleum, and it also reduces local air pollution, which is the key objective of the participants.

Reviewer 3:
The reviewer found the project to be relevant for objectives of diversifying cargo transport fuel sources and addressing adverse emissions conditions at ports, and thought that the presentation stated that 16,000 drayage trucks currently service the San Pedro Ports.

Reviewer 4:
The reviewer stated that each of the technologies under investigation demonstrates reduced petroleum consumption, across a broad spectrum of approaches.

Reviewer 5:
The reviewer expressed the view that, for zero-emission trucks to take off, it will take deployment projects like this to advance them with any speed.

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

Reviewer 1:
The reviewer commented that this project has a large budget, but the participants are doing a lot, including custom-building a set of trucks, using rather costly new technologies, so they will need all the money they have. The reviewer expressed hope that the trucks will operate well, so that they will actually be more efficient to operate than those they are replacing.

Reviewer 2:
The reviewer stated that the project has a sizeable budget, but is also relatively ambitious for producing seven vehicles with five different powertrain configurations, to explore the potential of zero- or near-zero-emission technologies for port drayage operation.

Reviewer 3:
The reviewer observed that any project involving hydrogen fuel cells is going to be rather expensive, and any project involving retrofitting trucks requires custom tailored engineering and labor-intensive effort. The reviewer expects this project to be expensive.

Reviewer 4:
The reviewer stated that this is a well-funded project.

Reviewer 5:
The reviewer stated that the program is ending soon, and resources are sufficient.

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 (EPRI)

Presenter
Sunil Chhaya, EPRI

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 project objectives are a good step to understand the impact of vehicle to grid (V2G) services on the vehicle.

Reviewer 2:
The reviewer noted that the approach is two-fold in design, focusing on both on-vehicle AC V2G, and off-vehicle DC V2G, and that both are important to understand, to address the full picture. The reviewer commented that the key enabler for this project is the Smart Power Integrated Node for integrating V2G, as well as renewable resources and stationary energy storage, all into a local controlled system. The reviewer further commented that this project also specifically targets the industry Society of Automotive Engineers (SAE) standards, which are key to successful implementation.

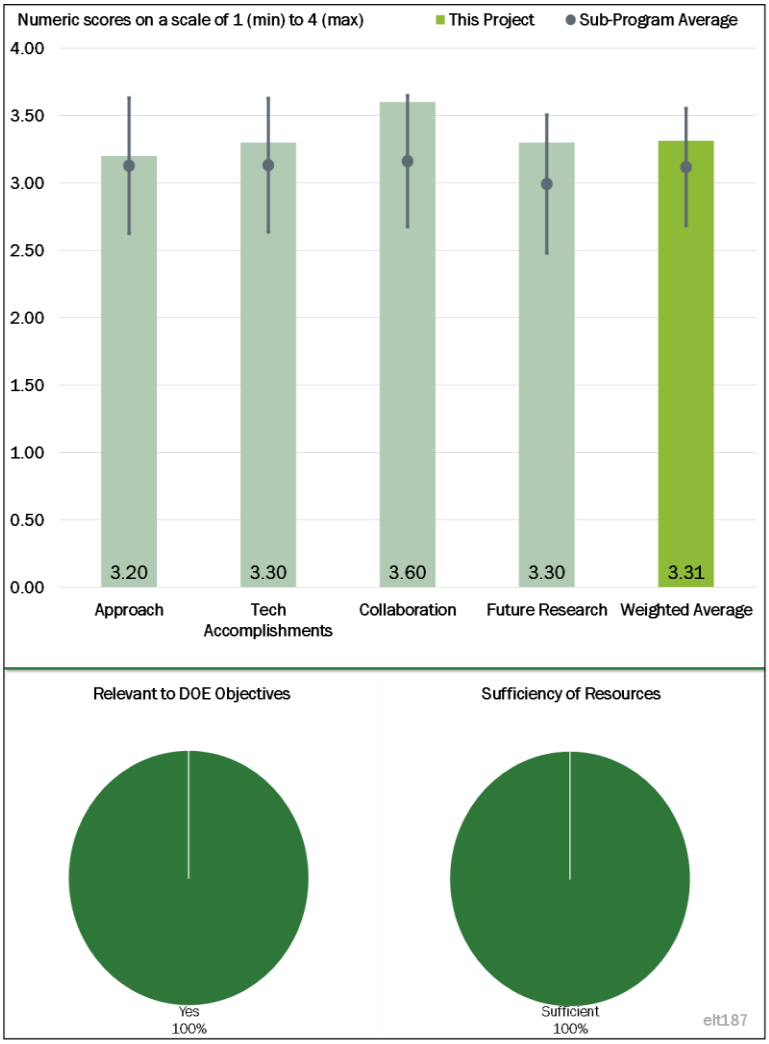

Figure 4-21 -Presentation Number: elt187 Presentation Title: Comprehensive Assessment of On- and Off-Board, Vehicle-to-Grid Technology Performance and Impacts on Batteries and the Grid Principal Investigator: Sunil Chhaya (EPRI

Reviewer 3:
The reviewer stated that the project is coming along well and barriers appear to be addressed.

Reviewer 4:
The reviewer commented that the proposed control method appears to be a good solution to optimizing power flow among distributed energy sources and plug-in electric vehicles (PEVs).

Reviewer 5:
The reviewer commented that the approach does not consider all available open standard architectures, such as ISO 15118, which is already a reference standard for J1772 CCS DC charging.

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

Reviewer 1:
The reviewer commented that the project has developed the capability to monitor and control transformers, which is significant for impacting local electricity supply. The reviewer noted that the project is currently operating four vehicles in the field as part of the demonstration and verification of this capability, and that multiple cost savings scenarios were developed, including baseline, with solar, and optimized with solar.

Reviewer 2:
The reviewer observed that the test vehicles are completed and deployed for testing, and the remaining activities are on track.

Reviewer 3:
The reviewer observed that almost all tasks are complete now, moving into the testing stage, and the test plan is completed. The reviewer further noted that on-vehicle V2G technology has been integrated and demonstrated on four vehicles.

Reviewer 4:
In the reviewer's view, the team appears to be making good progress on software development and the hardware demonstration.

Reviewer 5:
The reviewer noted that progress towards the battery durability impact study is not identified.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted that the project is well-coordinated among the team.

Reviewer 2:
The reviewer observed that separate organizations cover different aspects of the project, and the completion of various deliverables indicates the team is collaborating well and closely.

Reviewer 3:
The reviewer stated that the team includes a broad range of participants directly or for coordination, including the Electric Power Research Institute (EPRI)—the project lead—national laboratories, an OEM, a battery manufacturer, and control and systems firms, and that these appear to be exactly the parties necessary to make progress in this area.

Reviewer 4:
The reviewer stated that the project is on time and coordination with partners is not an issue.

Reviewer 5:
The reviewer stated that the team is working with several organizations to ensure the project is successful.

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 estimation, the team appears to have a good plan in place.

Reviewer 2:
The reviewer noted that no proposed future research is called out, and the evaluation is based on the remaining tasks listed for Budget Period 2. The reviewer found the tasks to be appropriate to answer the questions posed for the project.

Reviewer 3:
The reviewer stated that the project team has identified a detailed list of important remaining challenges and barriers. The reviewer added that, at this time, it is unclear how many can be addressed under this project, but it is a useful list to have.

Reviewer 4:
The reviewer observed that concerns over potential battery life were discussed, although the charging duty cycles appear to be low impact relative to vehicle level requirements. The reviewer further observed that the emphasis on addressing the V2G open standards was also highlighted and is critical. The reviewer noted that the project team is aware of the issues to overcome for the remainder of the project, and the issues to address ahead.

Reviewer 5:
The reviewer commented that Underwriters Laboratories (UL) qualification, or gap analysis, is essential for determining the industrialization path.

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

Reviewer 1:
The reviewer commented that the project enhances desirable characteristics and diminishes vulnerabilities of the U.S. energy infrastructure, while meeting environmental responsibilities.

Reviewer 2:
The reviewer noted that this project is focused on gaining a better understanding of key elements of integration between PEVs and the grid, to not only project costs and energy impacts, but also to improve control. The reviewer added that this will also assist in allowing greater integration of renewable energy sources. The reviewer commented that, as part of the overall effort, this project is working to address the specific lack of data on distributed energy resources, while looking at both on- and off-vehicle hardware, as well as standards verification. The reviewer added that all of these areas need to a better understanding to provide for a successful transition to greater effective deployment of EV technologies, a key objective for DOE.

Reviewer 3:
In the reviewer's estimation, this project has the potential to reduce peak power requirements and energy costs, while meeting the needs of PEV owners.

Reviewer 4:
The reviewer found that the project supports DOE investigation of PEV technologies and their impact on the electric grid.

Reviewer 5:
The reviewer stated that, for future connected, or V2G, vehicles to have an impact on energy consumption reduction, a number of technical approaches to the connectivity and interoperability need to be investigated and well understood. The reviewer found that this project addresses some of the hurdles in examining the potential impact such technologies could have in the future.

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

Reviewer 1:
The reviewer observed that resources appear sufficient at this time; however, depending on how many of the remaining challenges and barriers are accomplished under this project, there may be a future need for additional funding to address the remaining ones.

Reviewer 2:
The reviewer noted that there were well-established collaborators and resources.

Reviewer 3:
The reviewer stated that resources are sufficient for the project and good progress is being made.

Reviewer 4:
The reviewer stated that the project is on track with the given resources.

Reviewer 5:
The reviewer stated that the resources appear to be sufficient.

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 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 observed that the project team has the right approach for reaching the objective of developing a test prototype of a bi-directional wireless power transfer (WPT) system with large air gap between primary and secondary.

Reviewer 2:
The reviewer stated that the project had a well-defined strategy.

Reviewer 3:
The reviewer noted that this project started with evaluating a real-world application and proceeded to design a system that could prove the proof of concept for bi-directional wireless charging on MD trucks. The reviewer commented including a partner that would provide the true operational parameters provides realism to the design constraints and enhances the proof of concept. The reviewer noted that the project also explores how to do wireless with an 11" gap, 20 kW to the truck and 6.6 kW V2G.

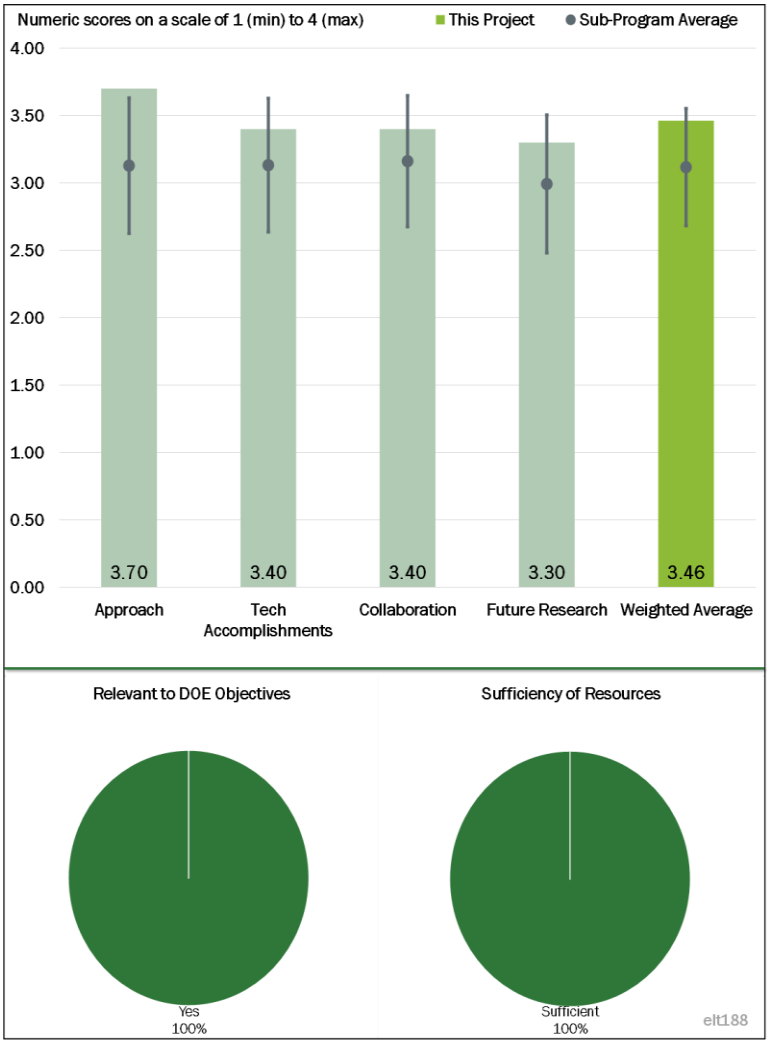

Figure 4-22 - Presentation Number: elt188 Presentation Title: Bi-Directional Wireless Power Flow for Medium-Duty Vehicle-to-Grid Connectivity Principal Investigator: Steven Sokolsky (CALSTART)

Reviewer 4:
The reviewer commented that, on the surface, this project does address many barriers with wireless conductivity (bi-directional), but most of the issues can be captured in the large air gap assessment and efficiencies. The reviewer added that the work and design appear to be very solid in engineering detail; however, great physical assessment will be necessary to confirm the efficiencies calculated.

Reviewer 5:
The reviewer commented that the basic technical questions are all covered. Not knowing anything, the reviewer questioned the robustness of the system for vibration, and the possibility of radiation leakage caused by the large air gap.

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

Reviewer 1:
The reviewer observed that the team has achieved its first-year milestone and appears to be on track for year 2 milestone. The reviewer added that the team presented ample proof that the simulated system design meets the requirements.

Reviewer 2:
The reviewer commented that this is a proof of concept design project which will deliver a prototype system, and that the project uses the constraints and operational parameters of the partner organization. The reviewer noted that the project is following typical engineering practices and has used simulation in the design requirements phase. The reviewer added that coupling coils are designed, the models of control systems are complete, and it was modeled across operating parameter ranges, i.e., gap. 93% efficiency predicted through simulations. The reviewer commented that these are all good technical accomplishments in the first period.

Reviewer 3:
The reviewer remarked that if the efficiencies can be confirmed in demonstration, this review will be elevated to outstanding.

Reviewer 4:
The reviewer commented that interoperability testing of primary and secondary sides can be at risk if primary and secondary sides are designed and tested independently, as presented. The reviewer added that parallel design, assembly and testing of primary and secondary sides should be considered.

Reviewer 5:
The reviewer remarked that it is difficult for a non-specialist to provide an informed review of the progress, because the presentation provided detailed charts without explanation of definition of variables. The reviewer added that it was hard to know how much of what was done was novel, and how much was standard. The reviewer recommended showing a state-of-the-art system and adding novel features in bright color so it is possible to review without expert knowledge, as well as telling the reviewers what is new and different, and why it was hard or interesting.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted that there were well-established, strong partners

Reviewer 2:
The reviewer remarked that the level of success is proportional to the depth of successful collaboration, and UPS and Workhorse are very motivated for energy savings in their operations.

Reviewer 3:
The reviewer commented that, for the intended objectives of the project, the collaborations are extremely good; however, to make it even stronger, the project needs an advisory partner who would cost and build the system in volume.

Reviewer 4:
The reviewer indicated that the project results are strong and the development appears to be well-coordinated. The reviewer noted that one possible improvement would be to show when specific project partners are engaged on the work plan; for example, the work plan should show symbols for design reviews that include the integration partners.

Reviewer 5:
The reviewer remarked that, so far, there is no evidence of collaboration. The reviewer added that it looks like ORNL has been modeling and designing energetically, but there is no evidence of inputs from the eventual customer. The reviewer assumed that some constraints on size, etc. were provided by partners and built into the design.

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

Reviewer 1:
The reviewer observed that the project had an appropriate go/no-go decision point at the completion of the simulation design phase and has an appropriate deliverable scheduled at the end of the bench testing phase.

Reviewer 2:
The reviewer commented that demonstration delivery by 2019 is aggressive with hardware, but tracking indicators appear on time.

Reviewer 3:
The reviewer stated that communication requirements and impact on the grid (loss of packages, speed of communication, etc.) are critical parameters to have evaluated.

Reviewer 4:
The reviewer noted that the process being employed outlined the work to be performed in subsequent phases. The reviewer added that the process is following a development method, but because no build partner or commercial collaborator is identified, the true challenge of knowing the ROI on such a system will not be explored.

Reviewer 5:
The reviewer remarked that future work is only described in broad generality. The reviewer recommended including an analysis of what the operating scenarios might be, such as what power is stored, where and when, what is it used for, etc., in future work.

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

Reviewer 1:
The reviewer remarked that the project certainly supports DOE objectives, and added that technologies such as bi-directional electric storage and power transfer are essential to demonstration of the efficiency that electrification may bring to society.

Reviewer 2:
The reviewer observed that the project supports DOE's overall objectives for advancing MD and HD EV charging capabilities. The reviewer added that this technology advances the state-of-the-art for wireless charging of MD and HD vehicles, especially in its bi-directional power transfer feature. The reviewer commented that it is important that DOE has an accurate characterization of bi-directional WPT to accurately assess the potential interactions of EVs with local microgrids, and possible interactions with—and impacts on—the performance and stability of the electric grid distribution network.

Reviewer 3:
The reviewer commented that the project supports electrification, which in turn supports petroleum reduction.

Reviewer 4:
The reviewer noted that the project focuses on infrastructure challenges, and will identify the opportunities for grid stability.

Reviewer 5:
The reviewer commented that the primary objectives do support the DOE objectives, as the project would enable the use of more fuel-efficient systems, namely electricity, for MD trucks. The reviewer added that the main question is what the strategy would be for when the vehicle batteries provide power to the grid, or are used in the sorting and loading facility to mitigate demand charges, and questioned what the gain is when the power goes back, and who uses it to obtain that cost advantage.

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 budget should be sufficient for design and build.

Reviewer 2:
The reviewer observed that the project has a very competent group with a proven track record to design, test and deploy a prototype system.

Reviewer 3:
The reviewer noted that the project has well established collaborators and resources

Reviewer 4:
The reviewer commented that, lacking any discussion to the contrary, the funding levels appear to be appropriate to the objectives described in the program.

Reviewer 5:
The reviewer noted that the resources have been adequate during the first phase, and the presenter gave no indication that the project had any concerns regarding resources.

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 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 this is a strong approach to this battery dominant hybrid truck development. The reviewer noted that there is a great deal of work going on with fully battery electric trucks and with their simplicity, rightly so, and added that hybrids by their nature take a rather complex powertrain of a diesel engine and its aftertreatment and add more complexity with the battery systems. In the reviewer's opinion, with range concerns, it will be very possible that hybrids will remain a solution. The reviewer commented that Cummins is doing a great job with this project.

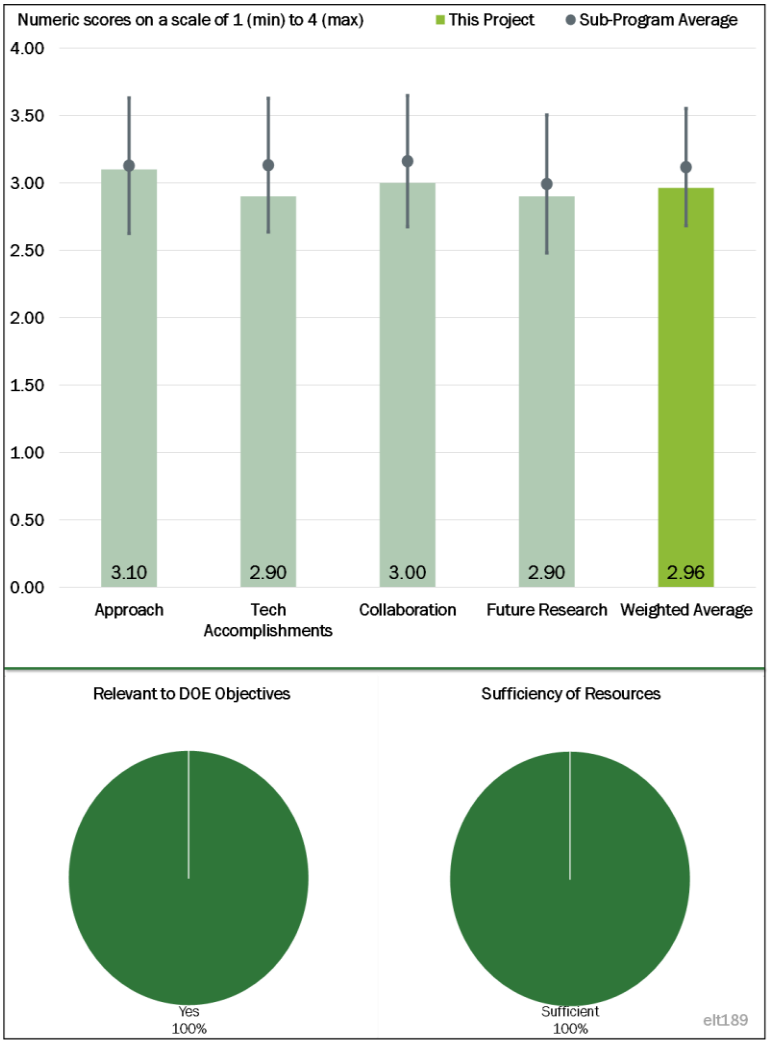

Figure 4-23 - Presentation Number: elt189 Presentation Title: Electric Truck with Range-Extending Engine (ETREE) Principal Investigator: John Kresse (Cummins)

Reviewer 2:
The reviewer observed that the project team focused heavily during the initial phase on development of key requirements, and commented that this was a good approach to minimize risk in later phases.

Reviewer 3:
The reviewer remarked that the approach seems to be on the right track; however, issues with the battery might delay the timing, making it too critical to achieve the validation demonstration phase.

Reviewer 4:
The reviewer commented that it is a $6 million program, and its relevance is related to risks associated with the real-world achievement of the fuel economy gains being sought. The reviewer noted that the approach does have a few things that may create limitations when the vehicle system is produced. First, a series of real-world routes would have been more appropriate to use as design criteria where the worst cases of the consolidated set of routes were used as design criteria. Second, it seems that because the engine choices were limited, it may have constrained the thinking regarding how to achieve the performance. The reviewer commented that other projects are using much smaller engines and have shown in similar types of simulations that they can achieve

the fuel economy objectives at much lower total system weight. The reviewer added that this is a low-risk approach when looking at meeting legacy customer expectations, which may need to change a bit if more significant gains are to be achieved.

Reviewer 5:
In the reviewer's opinion, this project is not an applicable solution for the current fast-changing environment because it is overly complicated and oversized, and noted that by the time it could become any kind of marketable solution, it will be outdated.

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 having to change battery suppliers is not good, but with so much development going on with batteries, it is not surprising, and this will likely happen to a small, but not inconsequential degree with production HEVs and battery-electric vehicles (BEVs). The reviewer commented that the team is managing this well and achieving program success with minimal delays.

Reviewer 2:
The reviewer commented that the project team needs to overcome the battery concerns, and added that the project did not address the potential performance concerns under cold weather conditions.

Reviewer 3:
The reviewer observed that significant loss of time occurred because of major shifts in major component subsystems, and restrictions on charging power for vehicles that have very large batteries is a business risk. In the reviewer's opinion, these decisions seem to be based on legacy thought processes where organizations just want nothing to change and all of the gains to be still available; however, this is not a plausible outcome very often, and it leads to putting artificial barriers in the road to progress. The reviewer commented that change can be designed that will result in a better system that may require just a bit of change, such as some small adaptation to accommodate diesel filter re-generation that can be programmed in. As examples, the reviewer noted a 4 month delay due to battery change, a targeted November 1, 2018 delivery to Frito Lay, Frito Lay's desire for low-level charging at low cost and the need for the range extender to reposition trucks in the fleet. The reviewer commented on good specification development, including 10 minute grade capability, 270 mile combined range, targeted 80 daily miles for the range extender to meet a high percentage of usage cycles, a 112 kWh lithium-ion 700 volt battery, 130 kW generator and 165 kW motor. The reviewer noted a 64.6 % fuel reduction in hardware-in-the-loop (HIL) test on the NREL 80-mile duty cycle test. NREL added 3400 lbs.

Reviewer 4:
The reviewer commented that the payback chart was unclear. The reviewer also noted that the presentation stated that battery failures were an issue and that thermal management was not needed on the batteries.

Reviewer 5:
The reviewer noted that the technical accomplishments are on track to the team's plan, and that the system is viable for the demonstration purposes, but seems to require significant modifications and upgrades to both hardware and software, to be commercially viable.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer observed that coordination on the project between team members appears to be good.

Reviewer 2:
The reviewer commented that the project has solid partners, and expressed interest in knowing what PepsiCo specifically thinks of the potential of this design, as they and other fleets will be the determining factor.

Reviewer 3:
The reviewer noted evidence of meeting technical goals and limiting timeline delays.

Reviewer 4:
The reviewer noted a full and complete group of collaborators, but there is an element of having some of them provide pre-conceived constraints to the development process. In the reviewer's opinion, it would have been better if the partners had been a bit more flexible, to actually test the new characteristics and then re-calibrate them out if there was a problem with operation in the real-world testing.

Reviewer 5:
The reviewer stated that payback viability was not demonstrated.

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 test plan and development change of the battery system show a good understanding of the need to build a robust system. The reviewer expects that the system as designed will be quite good in the test program.

Reviewer 2:
The reviewer commented on the strong plan moving forward.

Reviewer 3:
The reviewer noted that vehicle build and fleet testing are future plans for this project, and it will be important to create a robust data acquisition and analysis plan.

Reviewer 4:
The reviewer commented that battery payback, and timing to deliver vehicles and start the demonstration validation, are areas of concern that need to be addressed.

Reviewer 5:
The reviewer commented that the partners have the potential to develop solutions, but it would be a more cost-effective use of DOE funds to re-evaluate the outdated areas of the design. In the reviewer's opinion, streamlining or eliminating specific components may be a more realistic marketable approach.

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

Reviewer 1:
The reviewer found that this project meets overall DOE energy and fuel savings objectives.

Reviewer 2:
The reviewer commented that the project is relevant to the need for energy efficiency in transportation.

Reviewer 3:
The reviewer stated that electrified technology and commercializing it in large class vehicles are critical, and noted the need to monitor the execution carefully to assure staying on track.

Reviewer 4:
The reviewer commented that this program will create higher energy efficiency than the base system, and that if it does meet ROI objectives, it will be successful.

Reviewer 5:
The reviewer commented that this project definitely supports overall DOE objectives, but noted real range issues, and not just range anxiety. The reviewer stated that a diesel truck can run a week on one fuel-up, but BEVs will only be designed for a day's run.

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 resources are sufficient.

Reviewer 2:
The reviewer commented that resources appear adequate to meet overall project goals and tasks.

Reviewer 3:
The reviewer noted that the project seems to have sufficient resources, based on what was presented.

Reviewer 4:
The reviewer stated that these partners have all of the needed resources; they just have to apply them to the program.

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

Presenter
Matt Thorington, Bosch

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 found the approach to be satisfactory, based on the timing outline and the key deliverables, but commented that the demonstration phase of only 6 months is too narrow to allow for real-world testing and evaluation.

Reviewer 2:
The reviewer commented that the project is highly focused on development of the Bosch portion of the system, and noted that more involvement by other parts of the system may help to improve the overall efficiency for vehicle and end customer applications.

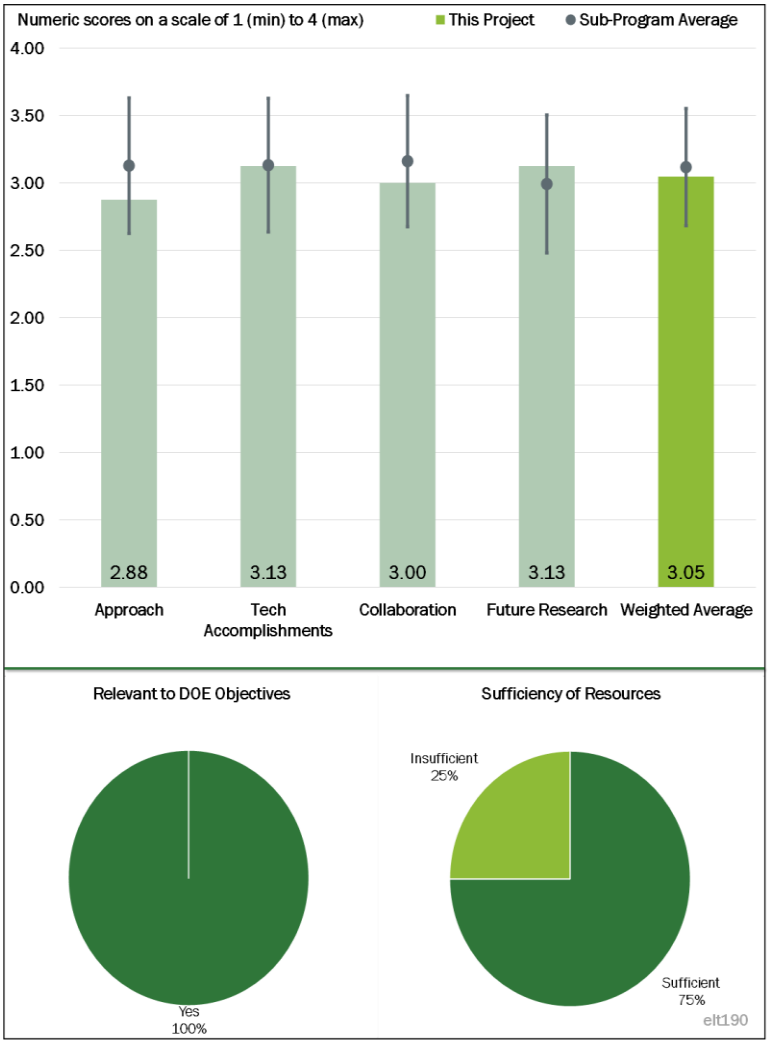

Figure 4-24 - Presentation Number: elt190 Presentation Title: Medium-Duty Urban Range Extended Connected Powertrain (MURECP) Principal Investigator: Alexander Freitag (Bosch)

Reviewer 3:
The reviewer stated that the diesel range extender engine adds complications with aftertreatment.

Reviewer 4:
The reviewer commented that the approach is not described for the identified 6 months of development for predictive control.

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 solid progress with good partner engagement.

Reviewer 2:
The reviewer found that the project technical tasks are on track for the agreed objectives.

Reviewer 3:
The reviewer commented that the assumed electric power rate and discharge power level are not included.

Reviewer 4:
The reviewer observed that there are many assumptions that are yet to be proven during the demonstration phase, and that the plan needs to be closely monitored to assure success.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer noted good collaboration across the project team, and found that Bosch brings great value and provides a very good base to the project.

Reviewer 2:
The reviewer noted that the project demonstrates a strong collaboration among the team members.

Reviewer 3:
The reviewer stated that it is not clear that the interaction between all the team members is occurring as effectively as possible, and questioned whether the other team members were partners or just suppliers.

Reviewer 4:
The reviewer commented that there are too many collaborators involved, and saw a need for Bosch to assure the activities and deliverables are closely monitored.

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

Reviewer 1:
The reviewer commented that the prototype build of two units and 6 months of customer testing is excellent for an effective evaluation.

Reviewer 2:
The reviewer noted good future potential, but stated that revisiting and updating the components, as technology is rapidly changing, should be included in the scope.

Reviewer 3:
The reviewer observed that critical challenges remain to be overcome, and that packaging and battery testing are critical. The reviewer also commented that the demonstration phase is limited to 6 months, and stated that this is too narrow to allow real-world testing.

Reviewer 4:
The reviewer indicated that it is not clear who is doing each task in the future research steps, and that the commercialization plan development process is also not clear.

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

Reviewer 1:
The reviewer stated that the project is very relevant to energy efficiency in transportation solutions.

Reviewer 2:
The reviewer noted that the project can help achieve a cleaner and more secure energy future.

Reviewer 3:
The reviewer found the project to be in line with DOE's green technology goals.

Reviewer 4:
The reviewer commented that the project is expected to reduce fuel and energy usage, which aligns with DOE objectives.

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

Reviewer 1:
The reviewer stated that the resources are sufficient to meet overall objectives.

Reviewer 2:
The reviewer observed that a number of critical activities are yet to be done, and recommended having a better focus on timing and execution.

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 stated that the approach to doing the work is outstanding, because the primary objectives are to increase acceptance of the MD EVs and reduce costs associated with building a MD EV for the delivery market. The reviewer added that the work plan and progress reported reflect that the requirements for improved fuel efficiency and commercial viability are the focus of the work being performed.

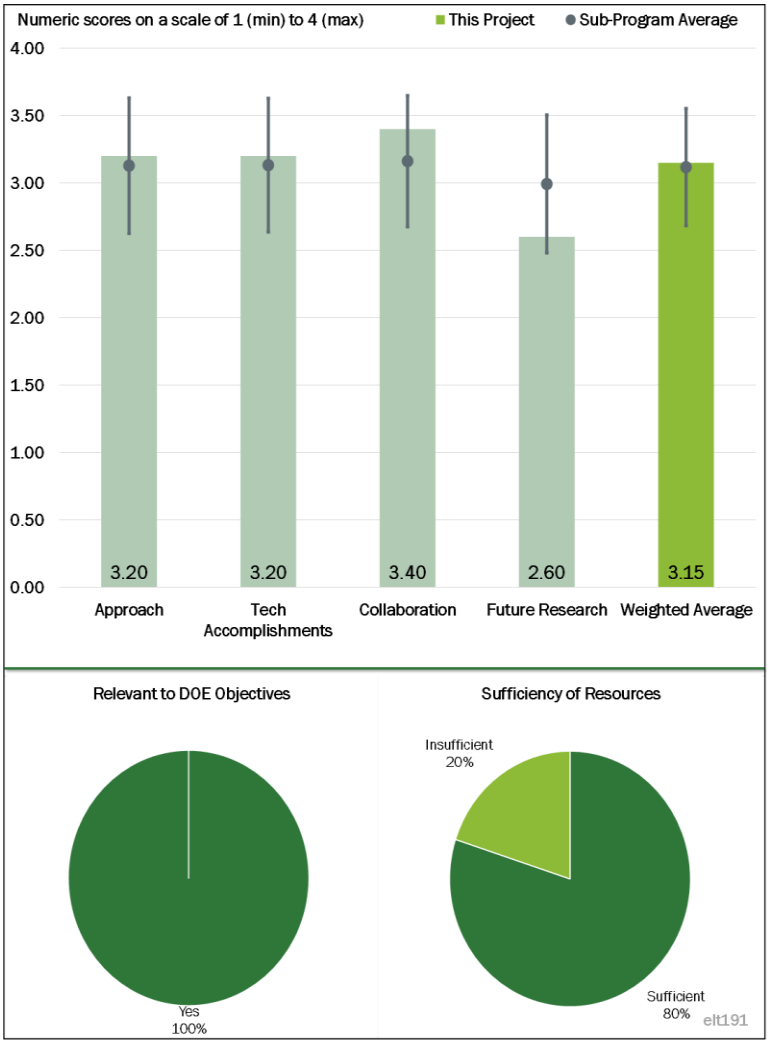

Figure 4-25 - Presentation Number: elt191 Presentation Title: Medium-Duty Vehicle Powertrain Electrification and Demonstration Principal Investigator: Wiley McCoy (McLaren)

Reviewer 2:
The reviewer stated that the approach is limited, but satisfactory to address the project's objectives.

Reviewer 3:
The reviewer commented that the approach is good, but there should have been more than the one objective defined for fuel efficiency; there should also be either reliability targets or vehicle performance targets, based on whatever the baseline vehicle is considered.

Reviewer 4:
The reviewer remarked that the project should look at a broader range of operations than those selected for Chula Vista, to ensure performance and results are representative across more of UPS' routes.

Reviewer 5:
The reviewer commented that the process used for selecting the electrification architecture is unclear, and that the authors should provide more details, to better assess whether the optimal solution was achieved, prior to the detailed design phase of the 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 found that the project seems to be on track to the committed schedule.

Reviewer 2:
According to the reviewer, it appears that the project team could have avoided a rework of the e-axle if they had been more rigorous in specifying component weight requirements. The reviewer found that the project team has created a design that meets their fuel efficiency improvement objective, and that the progress is taking a bit longer than initially scheduled, which is indicative that they are being true to their goal of producing a refined design that is capable of being commercialized. The reviewer added that the fact that the project team is taking the time to refine the design and incorporate feedback from the manufacturing team may be a good sign of the long-term impact of this project.

Reviewer 3:
The reviewer noted that some of the accomplishments are late, according to the original timeline, and commented that Slide 16 was a verbal update, but the contents should have been included in the presentation. The reviewer added that the metrics are all based on simulation data and HIL, and expressed an interest in seeing if the real-world testing will achieve the targets.

Reviewer 4:
The reviewer noted that the project team is trying to maintain the plan, in spite of challenges.

Reviewer 5:
In the reviewer's opinion, the project should better discuss the overall project objectives of a retrofittable design, or how easily it could be designed into other chassis; this was not discussed in enough detail.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer was impressed by the evidence of effective partner collaboration, based on the dropped alternative fuel requirement of the range extender. The reviewer noted that Ford wanted the requirement dropped, and the project team accommodated Ford's change request.

Reviewer 2:
The reviewer noted a very good list of partners which support project deliveries are collected.

Reviewer 3:
The reviewer noted good collaboration with the UPS team and chassis builder.

Reviewer 4:
The reviewer noted that the level of coordination between the team members seems to be good.

Reviewer 5:
The reviewer commented that the project information discussed was too focused on the PI's own business in general.

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

Reviewer 1:
According to the reviewer, it appears that the planned testing period will likely be shortened, due to slippage in the delivery schedule, and the reduced testing time may reduce some of the information value from the project, although it is not the end of the world; if the technology gets a commercial foothold, then reliability data will be developed later.

Reviewer 2:
The reviewer remarked that, because this system is expected to result in a commercialization demonstration, the team needs to give more consideration to other use cases, such as extreme environmental and operational schedules, to ensure that the design not only meets nominal program commitments, but also is capable of meeting all the marketplace demands.

Reviewer 3:
The reviewer commented that specific challenges were not identified, and future outreach was not outlined.

Reviewer 4:
The reviewer observed that future work was discussed with the test plan for four vehicles, but the commercialization plan and future for the technology build and deployment could be discussed in more detail.

Reviewer 5:
The reviewer commented that too many challenges lie ahead, with building the vehicles and starting the test; there are problems that need to be solved.

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

Reviewer 1:
The reviewer noted excellent relevance to DOE's early technology level development goals.

Reviewer 2:
The reviewer commented that the project supports DOE's objective to advance the state-of-the-art for MD EVs. The project introduces an on-board range extender to the MD EV that allows the vehicle to maintain SOC and extend its operating range. The reviewer noted that the project advances MD EV components (e.g., e-axle, range-extender) that will enable practical commercialization of the technology to meet real-world delivery vehicle requirements.

Reviewer 3:
The reviewer stated that the project is aimed at energy usage reduction, and therefore it aligns with DOE objectives.

Reviewer 4:
The reviewer indicated that the project supports the DOE objectives of electrification and increased efficiency and fuel economy.

Reviewer 5:
The reviewer found the project and the technology itself to be in line with DOE's objectives; however, the project team needs to focus on the targets to measure success.

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

Reviewer 1:
The reviewer stated that the project seems to be sufficiently funded to meet the project timing and deliverables.

Reviewer 2:
The reviewer stated that the resources seem sufficient.

Reviewer 3:
The reviewer noted that the project team is not requesting additional funding from DOE and the project will continue to completion; however, it appears that the project partners may have to make up for additional costs, as the budget numbers provided indicate that 13% of the funds are remaining, while 30% of the work remains to be done.

Reviewer 4:
The reviewer commented that there were too many challenges to overcome; the project needs more focus on timing, issues resolution, and demonstration testing.

Presentation Number: elt193
Presentation Title: Grid Modernization Laboratory Consortium: Vehicle-to-Grid Integration Pathway (GM0062)
Principal Investigator: Rick Pratt (Pacific Northwest National Laboratory)

Presenter
Rick Pratt, Pacific Northwest National Laboratory

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

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

Reviewer 1:
The reviewer stated that providing a demonstration of a V2G system that manages power consumption while meeting drivers' needs is an excellent method of promoting PEV adoption.

Reviewer 2:
The reviewer commented that because V2G integration involves infrastructure matters, the approach taken here with a broad range of national laboratories and industries is good. The reviewer found that the focus on use cases, demonstration, demand response, and demand mitigation is also quite agreeable.

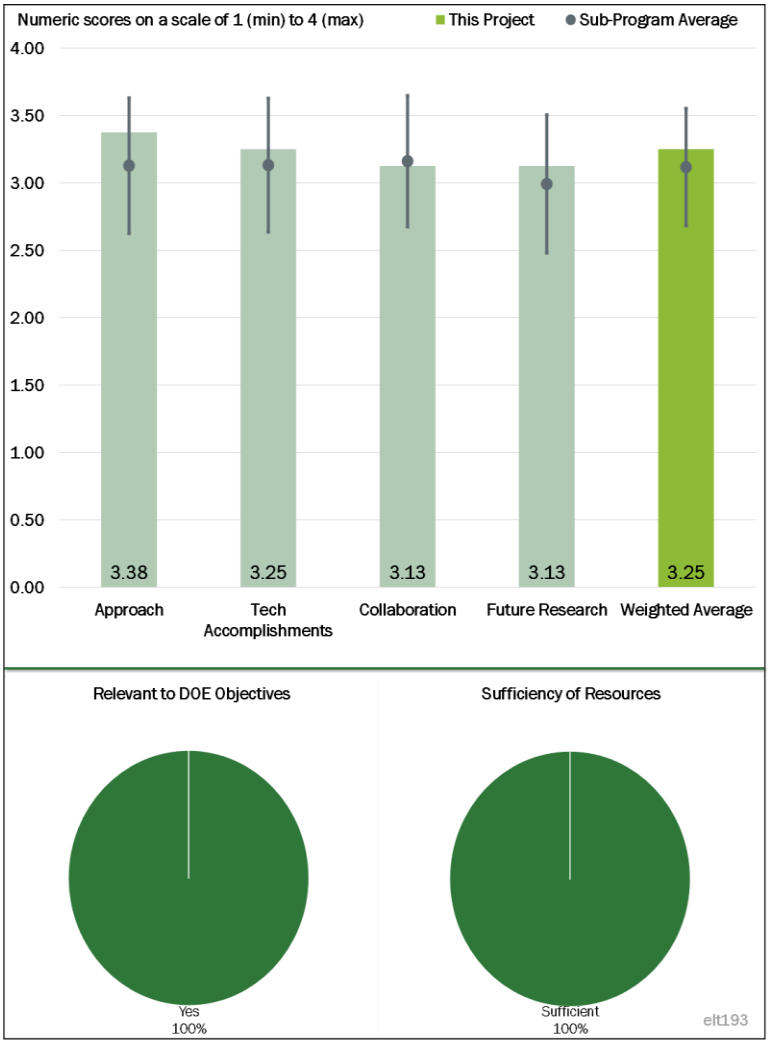

Figure 4-26 - Presentation Number: elt193 Presentation Title: Grid Modernization Laboratory Consortium: Vehicle-to-Grid Integration Pathway (GM0062) Principal Investigator: Rick Pratt (Pacific Northwest National Laboratory)

Reviewer 3:
The reviewer observed that the national laboratories focus their efforts on areas of strength for each, and the overall project is well-conceived.

Reviewer 4:
The reviewer remarked that the approach goes deeply into certain aspects of the problem as presented in the use cases for these national laboratory buildings; however, it will not include enough variables on user requirements that may exist in a more varied-use building in the commercial world. For the environment being studied, the project has good use cases, the project team included the input of stakeholders, controlled versus uncontrolled charging implications and challenges, and the criteria for demand charges. The reviewer noted that a more commercial environment will have more varied-use cases—like visitors that arrive in EVs for 1 hour—that can create many new issues that these analyses may not cover.

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 that the team is making good progress on the demonstrations and simulations of case studies.

Reviewer 2:
The reviewer found the charge demand response and mitigation demonstration to be good. The reviewer noted that the economic analysis numbers were relevant for certain specific assumptions, and recommended checking how the resulting numbers would be affected by different assumption sets (parameter sensitivity).

Reviewer 3:
The reviewer noted that the presenter spent time showing why users need to avoid demand charges due to costs; however, this was obvious and could have been briefer. Further, the economic analysis that showed savings included only averages and therefore was not really well done. The reviewer added that, in questioning, the presenter indicated there was much more behind the slide, but those things should have been shown. In addition, the various use profiles of the vehicles—different commute distances and SOC upon arrival—need to be statistically sampled and used to develop the solution logic for controlling charging and demand charges simultaneously.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer stated that the collaboration among a broad range of industries and national laboratories is very good.

Reviewer 2:
The reviewer commented that the team is communicating with several industry advisors to prioritize use cases, and the team is working with several other national laboratories to ensure successful demonstrations.

Reviewer 3:
The reviewer commented that the project team is all DOE internal collaborations, and questioned where the outside stakeholders are that affect this project, such as the utilities and commercial building control systems providers.

Reviewer 4:
The reviewer noted that, as presented, there does not appear to be a deep level of close and frequent coordination between the national laboratories, and suggested that the project could benefit from more frequent interaction between the teams.

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

Reviewer 1:
The reviewer observed that the team appears to have a good plan in place.

Reviewer 2:
The reviewer stated that the plan for future research is good, and noted that having a plan to disseminate results and findings from the study to key players and get feedback on conclusions would be beneficial.

Reviewer 3:
The reviewer stated that the proposed future research items are good. The reviewer added that it might be a good idea to classify the numerous use cases and use scenarios to understand the various possibilities in a structured manner. The reviewer also noted that it looks like the study is assuming a normal operating situation, and, although the probability would be low, a V2G integrated system could play a significant role in a badly abnormal situation, such as a region-wide power outage or natural disasters. The reviewer is wondering if such abnormal scenarios are in the scope of this project.

Reviewer 4:
The reviewer commented that, with the shortcomings in the approach, the future work, as described, will not be applicable beyond the constrained use profiles being studied. The reviewer added that this project needs to expand itself beyond the DOE building scenarios being studied.

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

Reviewer 1:
The reviewer noted that V2G integration is becoming a more and more important theme, as EVs gain deeper market penetration and as more charging infrastructure is constructed; renewable energy distributed power infrastructure and smart and/or zero-energy buildings are also linked. The reviewer commented that these background and ongoing changes make this study more and more relevant.

Reviewer 2:
The reviewer commented that energy demand on the grid side is important, and it is good to see DOE being proactive to potential failure modes for adoption of hybrid and EVs.

Reviewer 3:
The reviewer stated that this project has the potential to increase the PEV adoption rate.

Reviewer 4:
The reviewer indicated that, yes, the subject is relevant, but as configured this project will have narrow utility; there needs to be an expansion of the stakeholder base to understand more complicated use cases for vehicles and charging scenarios to create a wide-ranging use of the 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 indicated that resources appear to be sufficient to execute the objectives of this project.

Reviewer 2:
The reviewer found that the project appears to have sufficient resources.

Reviewer 3:
The reviewer commented that it looks like the resources are currently sufficient, considering the proposed future research.

Reviewer 4:
The reviewer stated that the resources are sufficient, but are bordering on being excessive for what the outcome may yield. The reviewer suggested that more be done with these resources by employing more stakeholders and use cases.

Presentation Number: elt194
Presentation Title: Grid Modernization Laboratory Consortium: Systems Research for Standards and Interoperability (GM0085)
Principal Investigator: Don Scoffield (Idaho National Laboratory)

Presenter
Don Scoffield, 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.

Reviewer 1:
The reviewer commented that the "aggregator concept in the approach allows the team to get a handle on what is a somewhat open-ended question defined as a barrier.

Reviewer 2:
The reviewer commented that this approach will allow reduced peak power demand by controlling the rate of charging PEVs.

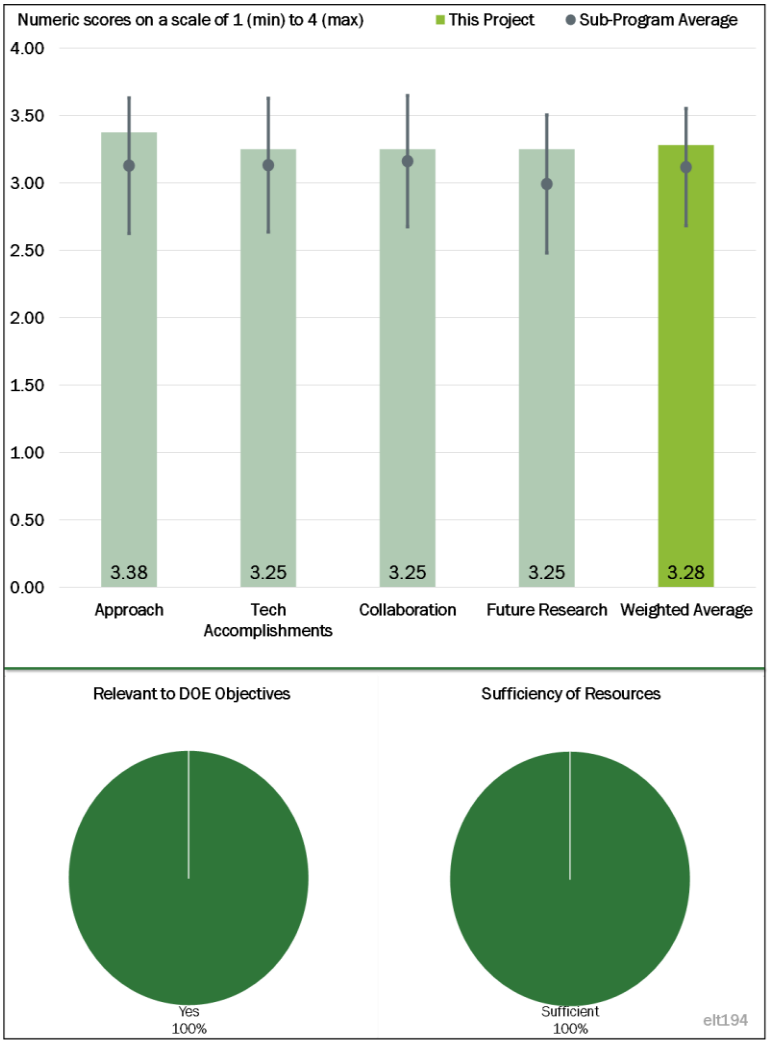

Figure 4-27 - Presentation Number: elt194 Presentation Title: Grid Modernization Laboratory Consortium: Systems Research for Standards and Interoperability (GM0085) Principal Investigator: Don Scoffield (Idaho National Laboratory)

Reviewer 3:
The reviewer observed that the project intends to develop an aggregator platform that understands how charging can be controlled at the commercial building and/or the residence level. For commercial buildings, the aggregator control is within the building level. The residence real-time digital simulators (RTDs) connect the activity of all agent vehicles, and the aggregator is controlling charging thru RTDs with no building controller in between, as in commercial buildings.

The reviewer remarked that the research is an attempt to create a tool to solve the problem of how uncontrolled charging can affect power demand and cost, and therefore affect the adoption of zero-emission vehicles. The reviewer found this to be a good approach to try to find a solution to this issue.

Reviewer 4:
The reviewer noted that the slide titled "Approach: Quantify Benefit of Controlling PEV Charging" lists the following bullet: "After the simulations have been run, the economic benefits of controlling PEV charging will be quantified." In the reviewer's opinion, this bullet is not accurate in that it overstates the degree of economic analysis that the project has performed by an order of magnitude. The reviewer added that this

project addresses a limited economic analysis that is confined to the distribution feeder expansion costs associated with aggregator-controlled charging.

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

Reviewer 1:
The reviewer observed that progress has been excellent, with some interesting results showing the benefit of the aggregator concept.

Reviewer 2:
The reviewer stated that the project has made effective progress in that it has performed simulations and come to specific preliminary conclusions regarding potential benefits of aggregator controlled PEV charging. The reviewer added that the project has produced a clear story that deserves further refinement and validation.

Reviewer 3:
The reviewer found that the team has made good progress on modeling of the system and evaluating case studies.

Reviewer 4:
The reviewer noted that, so far, the progress has been to characterize PHEV in three use cases, to understand vehicle reactions that affect the grid. The reviewer observed that the first version of the aggregator communicates with EVs directly, and stated that this is reasonable progress for the time expended, and that the communication needs to be expanded to the building control units, where applicable, and to the utility.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer observed that an appropriate group of partners has been assembled, and the advisory board of utilities is an excellent adjunct source of feedback on the work.

Reviewer 2:
The reviewer stated that it is clear that the partners have collaborated to establish the use cases and development of the scenarios for the initial simulations, and noted that the schedule indicates the collaboration between the partners is going to increase significantly to accomplish the next phase of development.

Reviewer 3:
The reviewer found that the team is coordinating several organizations to ensure the project is successful.

Reviewer 4:
The reviewer commented that the collaborations are narrow and mostly laboratory-based, and added that significant and active input from the utility is needed for the successful development of the capabilities within the aggregator.

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

Reviewer 1:
The reviewer commented that the next steps are logical follow-ups to the work already carried out.

Reviewer 2:
The reviewer found that the team has a good plan in place.

Reviewer 3:
The reviewer stated that the future research needs to have the aggregator be integrated or interconnected with the utility operation that supplies the building units, and possibly the building control systems.

Reviewer 4:
During the presentation, there was a statement that led the reviewer to believe that each of the national laboratories are doing their own, but similar, work in parallel, and that this may result in some duplication of effort. The reviewer suggested that it would be useful if the project could incorporate consideration of non-PEV building loads and building transformer cooling requirements into its scheduling of PEV charging.

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

Reviewer 1:
The reviewer commented that the project supports DOE's investigation of the impact of PEVs on the electric grid. The reviewer added that the results help to answer critical questions about how well the existing grid infrastructure can support increased charge demand from PEVs and possible solutions to mitigate the impact of that demand.

Reviewer 2:
The reviewer stated that the project is relevant because it is an attempt to solve an issue that may impede the adoption of high-volume EVs.

Reviewer 3:
The reviewer noted that this project is exploring the feasibility and benefits of coordinated "central" control of PEV populations by a third-party aggregator. The reviewer commented that developing business cases related to PEV charging control strategies support DOE's objective to develop EV technologies that minimize the impacts of EV charging on the stability and reliability of the electric grid.

Reviewer 4:
The reviewer remarked that this project has the potential to reduce peak power requirements while meeting the needs of PEV users.

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

Reviewer 1:
The reviewer stated that the project is on track with the available resources.

Reviewer 2:
The reviewer commented that the project is funded with sufficient resources.

Reviewer 3:
The reviewer commented that the resources appear to be sufficient.

Reviewer 4:
The reviewer observed that the resources appear to be burning at a rate slightly faster than the schedule would warrant. The reviewer added the presentation indicates that 40% of the work remains, but it appears that the team has approximately one-third of the total project funds remaining; however, based on the work descriptions, the partners should be able to fit the remaining work to the available funds.

Presentation Number: elt196
Presentation Title: Grid Modernization Laboratory Consortium: Diagnostic Security Modules for Electric Vehicle-to-Building Integration (163)
Principal Investigator: Kenneth Rohde (Idaho National Laboratory)

Presenter
Kenneth Rohde, Idaho National Laboratory

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

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

Reviewer 1:
The reviewer declared this an excellent approach to using available resources to develop hardware that demonstrates the cybersecurity system principles in PEV charging applications.

Reviewer 2:
The reviewer stated that this is a very good approach to a very important issue that needs to be resolved before we can use a charging system safely for EVs.

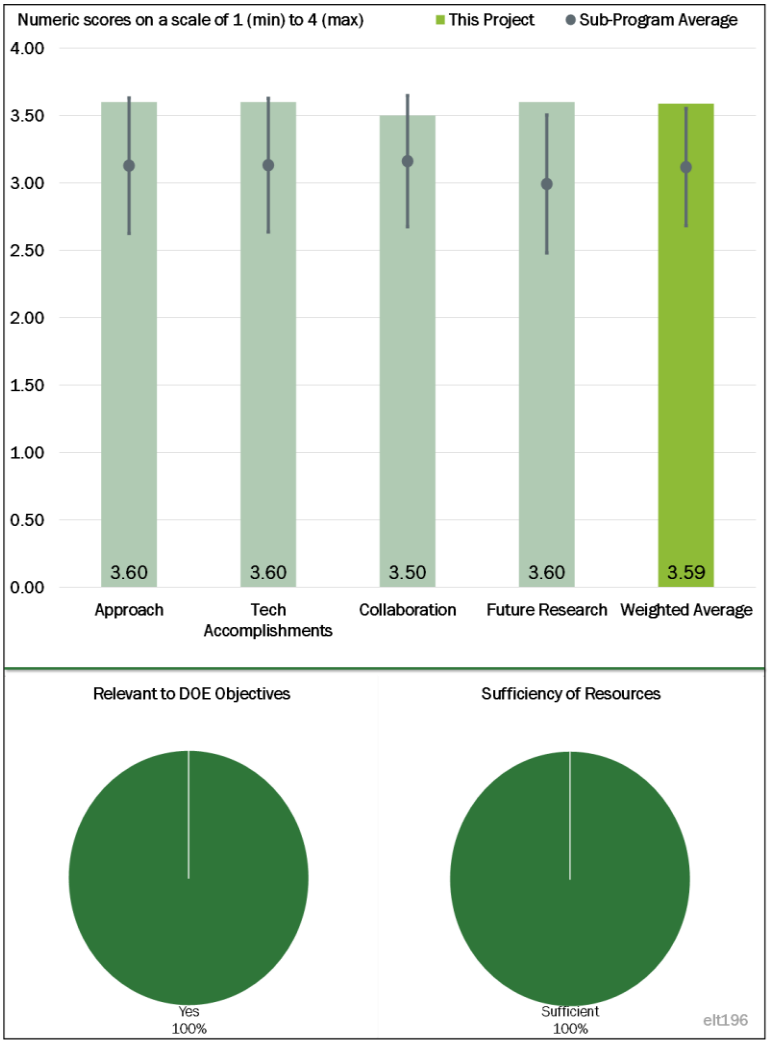

Figure 4-28 - Presentation Number: elt196 Presentation Title: Grid Modernization Laboratory Consortium: Diagnostic Security Modules for Electric Vehicle-to-Building Integration (163) Principal Investigator: Kenneth Rohde (Idaho National Laboratory)

Reviewer 3:
The reviewer stated that, fundamentally, programs to develop or evaluate vehicle-to-infrastructure (V2i) charging security are addressing an open issue, or gap, in the EV space that this project directly is addressing. The reviewer added that Idaho National Laboratory appears to be extremely qualified in its assessment of the technology and approach to the problem.

Reviewer 4:
The reviewer commented that this is an area in need of research, and this project fulfills a glaring need to secure the vehicle communication systems from cyberattack, and more importantly from transferring an attack to a building unit or to the grid. The reviewer added that the approach is to apply advanced cyber methods to these systems, knowing that there could be multiple system variations that need to be accommodated.

Reviewer 5:
The reviewer found this project to be a good approach to a critical area of charging and addressing key technical issues.

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

Reviewer 1:
The reviewer commended the project team for great work, and progress that is right on track.

Reviewer 2:
The reviewer commented on the large strides made in defining and implementing the system, starting from scratch.

Reviewer 3:
The reviewer stated that the project appears to be well-focused, and it demonstrated logical progression towards success. The reviewer added that deployment and demonstration of the diagnostic security module (DSM) will be critical in the project path, and it appears that this is being completed soon to overcome issues early enough to not jeopardize the project with delays.

Reviewer 4:
The reviewer commented that the project technical tasks are on target for meeting project timing and objectives.

Reviewer 5:
The reviewer commented that the project team has developed a framework to monitor the security state of the systems and provide information on risks to the building system. The reviewer noted that this project is not intended to produce a system to be sold and marketed, but to give system functionality guidance to stakeholders, and create knowledge for future system deployment. The team intends to demonstrate the project at CyberAuto 2019. The reviewer added that the team is working with the electric vehicle supply equipment (EVSE) provider, ChargePoint, using early specification EVs to understand how communications with the building need to be secured.

Question 3: Collaboration and Coordination Across Project Team.

Reviewer 1:
The reviewer commended the project for its great collaboration and team members.

Reviewer 2:
The reviewer commented that ChargePoint is a very good collaborator to have in this space, and noted good use of the other team members to complete various parts of the project.

Reviewer 3:
The reviewer stated that most critical is the ChargePoint coordination, which will lead to hardware delivery, and added that the project has great credibility, with involvement from other national laboratories and some academia.

Reviewer 4:
The reviewer noted that collaboration does not seem highly coordinated, but it is sufficient to progress the overall objectives of the project at this stage; however, the reviewer would expect closer coordination and alignment for future efforts.

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

Reviewer 1:
The reviewer commented that the project team has laid out a very straightforward plan for program completion to the proof of concept level that was described in the presentation.

Reviewer 2:
The reviewer stated that future plans are very relevant.

Reviewer 3:
The reviewer commented that the next steps are reasonable tasks for this project.

Reviewer 4:
The reviewer stated that the plan for future research is good.

Reviewer 5:
The reviewer noted that the project outline through 2019 appears to be technically aggressive without over-projecting, and expressed uncertainty about what, if any, post project research may be needed.

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

Reviewer 1:
The reviewer stated that security of the applications of advanced technology is key to its success, and that if there are vulnerabilities identified in the field that jeopardize the building or grid, then strategic charging, one of the goals of electrification, cannot be achieved. The reviewer added that this project is proactive to this endeavor.

Reviewer 2:
The reviewer commented that securing the energy grid is a key aspect critical to the DOE mission, as electrification continues to penetrate the marketplace.

Reviewer 3:
The reviewer indicated that yes, this project is the kind of block and tackling necessary to make PEV deployment successful in the long run.

Reviewer 4:
The reviewer stated that the project supports energy efficiency because it supports the secure deployment of new systems in the marketplace.

Reviewer 5:
The reviewer commented that EVs will not work without safe charging.

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

Reviewer 1:
The reviewer stated that there are proper resources for project.

Reviewer 2:
The reviewer noted that the project is on track with the available resources.

Reviewer 3:
The reviewer commented that, in the absence of indication to the contrary, this project appears to be sufficiently funded to meet the objectives described.

Reviewer 4:
The reviewer stated that broad based resources and technical expertise are included in the program.

Reviewer 5:
The reviewer commented that funding seems sufficient to meet project objectives.

Acronyms and Abbreviations

°C	Degrees Celsius
3-D	Three dimensional
AC	Alternating current, air conditioning
AMR	Annual Merit Review
ATF	Automatic transmission fluid
B	Magnetic-flux density
BEV	Battery electric vehicle
BH_{max}	Maximum energy product
BP	Budget Period
Br	Residual induction
CNT	Carbon nanotubes
CPC	Capacitive power coupler
CRADA	Cooperative Research and Development Agreement
DC	Direct current
DOE	U.S. Department of Energy
ECCE	Energy Conversion Congress and Exposition
ECV	Electric commercial vehicle
EDV	Electric drive vehicle
EETT	Electrical and Electronics Technical Team
ELT	Electrification Technologies
EM	Electromagnet
EV	Electric vehicle
FFRDC	Federally Funded Research and Development Center
FY	Fiscal Year
GVW	Gross vehicle weight
H	Magnetic-field strength
Hci	Intrinsic coercive force

HD	Heavy-duty
HIL	Hardware-in-the-loop
HESM	Hybrid excitation synchronous machine
HEV	Hybrid electric vehicle
HPC	High-performance computing
HRE	Heavy rare earth
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
IMS	Insulated metal substrate
IPM	Interior permanent magnet
Kg	Kilogram
kW	Kilowatt
kW/l	Kilowatt per liter
kWh	Kilowatt-hour
LCD	Levelized cost of driving
m/s	Meters per second
MD	Medium-duty
MGOe	Megagauss Oersted
MHz	Megahertz
M_S	Saturation magnetization
NA	North American
NREL	National Renewable Energy Laboratory
Oe	Oersted
OEM	Original equipment manufacturer
ORNL	Oak Ridge National Laboratory
PF	Power factor
PHEV	Plug-in electric vehicle
PI	Principal Investigator

PM	Permanent magnet
PTO	Power takeoff
R&D	Research and development
ROI	Return on investment
SCAQMD	South Coast Air Quality Management District
SiC	Silicon carbide
SME	Subject matter expert
SOC	State of charge
T	Tesla
TPG	Thermal pyrolytic graphite
UCC	Ultra-conductive copper
V2G	Vehicle-to-grid
VTO	Vehicle Technologies Office
WFSM	Wound-field synchronous machine

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