2. Electric Drive Technologies

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

The Electric Drive Technologies R&D subprogram funds programs with partners in academia, national laboratories, and industry. The subprogram emphasizes material, device, and component innovations to significantly reduce the cost, weight, and volume of electric drive systems. The subprogram supports material and process innovations to achieve significant cost reduction in power electronics, electric motors, and integrated electric drive systems by supporting two areas: Electric Drive Technologies Research and Electric Drive Technologies Development.

Subprogram Feedback

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

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

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

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

Question 3: Were important issues and challenges identified?

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

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

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

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

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

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

Question 10: Has the program area engaged appropriate partners?

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

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

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

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

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

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

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

Presentation Number: edt000 Presentation Title: Overview of the DOE VTO Electric Drive Technologies R&D Program
Principal Investigator: Steven Boyd (U.S. Department of Energy)

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

Reviewer 1:
The reviewer asserted that the program area was adequately covered. The various technology areas and their long-term progression and impact on overall performance targets have been covered.

Reviewer 2:
The reviewer agreed that the program area was adequately covered in the presentation.

Reviewer 3:

The reviewer stated yes.

Reviewer 4:
The reviewer commented that this review covered the electric vehicle power electronics, electric drive system, and charging infrastructure. The reviewer noted that the electric drive (ED) area was adequately covered.

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

Reviewer 1:
The reviewer stated that there is a very good balance and a clear roadmap in terms of developing and maturing the different technology areas to meet the various performance targets.

Reviewer 2:
The reviewer observed that near- and mid-term research is emphasized which is appropriate given the market need for improved electric drive systems to drive faster market penetration. Long-term research efforts are focused on permanent magnet materials and soft magnetic material modeling. This is appropriate given the support that is available for long term component research available in other agencies.

Reviewer 3:
The reviewer stated yes, and clearly observed more focus on mid- to long-term approaches, which should be the focus.

Reviewer 4:
The reviewer stated yes; the ED system cost and performance target are clearly called out for 2020 and 2025.

Question 3: Were important issues and challenges identified?

Reviewer 1:
The reviewer enthusiastically stated yes.

Reviewer 2:
The reviewer agreed that important issues and challenges were identified; the challenges are clear and there is a good mix of projects to address them.

Reviewer 3:
The reviewer said yes, and added that there is an opportunity to tie challenges together. For example, this reviewer highlighted progression to greater than 600 volt (V) batteries coupled with standards development for direct-current (DC) fast charging at voltage levels greater than current Society of Automotive Engineers (SAE)

1772 and Chademo standards, which are presently limited. As another example, the reviewer inquired about what should be the maximum high-power charging 350+ KW power charge voltage.

Reviewer 4:
The reviewer noted that key challenges around cost, power, and power density were identified. Challenges pertaining to reliability, lifetime, and sustainable manufacturing were not explicitly identified.

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

Reviewer 1:
The reviewer enthusiastically stated yes.

Reviewer 2:
The reviewer stated yes, there is a good plan and roadmap to address the issues and challenges.

Reviewer 3:
The reviewer noted that categories of technology solutions were identified for addressing challenges in reducing cost, improving power capability, and increasing power density. There was a clear link between the technology solutions and the issues and challenges.

Reviewer 4:
The reviewer noted that the $6/kW 2025 Electric Drive Technology (EDT) system target for a 100 kW EDT system and a 100,000-unit annual production volume is certainly a challenge. The reviewer recommended having a targeted bill of material with cost targets by component to address issues by specific component technology with basic research focus to address the specific challenge of that component.

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

Reviewer 1:
The reviewer stated yes, the progress compared to the previous year has been clearly identified.

Reviewer 2:
The reviewer stated yes and noted that the 100kW traction inverter cost targets are benchmarked between 2017, 2020, and 2025.

Reviewer 3:
The reviewer noted that a chart presenting multi-year progress, achieved and forecast, for reducing cost was presented. The status of each technology focus area was presented. There was not a year-to-year comparison between 2016 (previous year) and 2017 (current year) results.

Reviewer 4:
The reviewer stated that progress was less clearly benchmarked against the previous year. The reviewer looked at the presentation file from 2016 to know what was reported in the previous year. The reviewer noted that an area of improvement would be to have a more specific slide to highlight areas from 2016 that are continuing and, more importantly, what was found to not be practical technology to continue as a focus area for 2017 and beyond.

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

Reviewer 1:
The reviewer stated yes, there is a good mix of projects that clearly address the problems and barriers VTO is trying to solve.

Reviewer 2:
The reviewer stated yes, the projects are addressing the goal of reducing the cost of the electric drive system to $6/kw by 2025. There is a broad portfolio of projects in power electronics and electric machines addressing this challenge from a wide perspective.

Reviewer 3:
The reviewer stated yes, the projects in this technology area are addressing the broad problems and barriers that VTO is trying to solve and observed that certainly the biggest challenge of cost should continue to guide the technology area.

Reviewer 4:
The reviewer stated yes, the projects in this technology area are addressing the broad problems and barriers that VTO is trying to solve. The reviewer noted that key technologies such as silicon carbide (SiC) semiconductor efficiency improvements, non-rare-earth materials for motors, and film capacitors for traction inverters are listed to break through.

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

Reviewer 1:
The reviewer stated yes, the program area is focused on the right technology areas. It is well-managed and shows a path to addressing VTO's needs

Reviewer 2:
The reviewer stated yes, the program area appears to be focused, well-managed, and effective in addressing VTO's needs.

Reviewer 3:
The reviewer stated yes, the program is clearly focused on the VTO's needs. The electric drive system is a key component of the VTO's goal of increasing energy efficiency in the automotive industry by funding the development of technology that will accelerate the market penetration of electric vehicles EVs). The program appears to be well-managed in that an appropriate allocation of resources has been made between power electronics and electric machines, and that the performance targets for each technology have been clearly defined. The program appears to be effective in that the majority of projects appear to be making significant progress towards meeting their targets.

Reviewer 4:
The reviewer stated yes, the program area appears to be focused, well-managed, and effective in addressing VTO's needs. An improvement could be a list of projects and funding level as an appendix to show how the fiscal year (FY) budget is being spent to address VTO needs. So what was spent on what projects in 2016 versus the reduction in 2017 to give us an idea what program areas are being emphasized.

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 noted that the key strength is the diversification and broad range of technology areas covered, all of which are critical to meeting the performance targets and VTO's needs. The reviewer stated that there are no key weaknesses but more verification of the technologies developed in an actual system would add more value.

Reviewer 2:
The reviewer commented that a key strength of the projects in this focus area is the support of development of advanced functional materials (semiconductors, magnetics, capacitors, insulators, and conductors) with

properties optimized for high-power density and high-efficiency electrical machines. The development of these materials in concert with the development of power electronic and machine systems promotes fertile cross-collaboration between research and engineering communities that otherwise rarely interact. This accelerates the development of materials technologies that meet system level needs, and expands the design space of machines that can quickly take advantage of unique properties of new materials. The development of wide bandgap (WBG) power modules stands out as an area where the materials and systems teams have effectively collaborated.

The reviewer noted that a weakness of this program area is that the path to market of many of the new technologies are not always completely clear. Deeper involvement by material and component manufacturers, both domestic and foreign, would accelerate the commercialization of these new technologies to the scale needed to supply the automotive and mobility industries. The development of polymer multilayer capacitors is a potentially transformational technology that could fail to achieve market acceptance if the development of the production-scale equipment is not successful.

Reviewer 3:

The reviewer identified key strengths as increasing DC fast charge technology and WBG technologies. The reviewer identified a weakness as lack of cross connection to motor technology and proposed a WBG enabled motor or a WBG enabled DC fast charging topology.

Reviewer 4:

The reviewer stated that the overall system cost target is clear but the sub-module cost target needs further development.

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

Reviewer 1:

The reviewer state yes, the projects are novel and show promise in terms of addressing the barriers. In some cases, the practical aspects need to be better taken into consideration to make sure that there is ultimately a good path for commercialization.

Reviewer 2:

The reviewer noted that there is a range of approaches being pursued with levels of novelty that vary with the risk being undertaken. Development of codes and standards are an example of a low-risk approach that will likely lead to modest, but entirely necessary, improvements in marketability of the power electronic and electric drive technologies. Truly innovative efforts, such as the computational modeling of soft magnetic materials, are addressing foundational problems in the physics of magnetic materials. Success is not guaranteed, and may depend on the status of high-performance computing technology. However, the reward for successfully innovating in this area could be a substantial improvement in the efficiency of systems that use soft magnetic materials.

Reviewer 3:

The reviewer stated yes, these projects represent novel and/or innovative ways to approach these barriers and cautioned that the approaches might be so novel that they may be difficult to manufacture in some instances.

Reviewer 4:

The reviewer stated yes, these projects represent novel and/or innovative ways to approach these barriers.

Question 10: Has the program area engaged appropriate partners?

Reviewer 1:

The reviewer responded yes, the program area has engaged appropriate partners.

Reviewer 2:
The reviewer responded yes, the program has engaged appropriate partners in industry, academia, and national laboratories. More involvement by foreign and domestic component and material manufacturers may accelerate the market penetration of these technologies. More coordination with National Aeronautics and Space Administration and U.S. Department of Defense laboratories would promote allocation of resources that are not being addressed in aerospace and naval electrification programs.

Reviewer 3:
The reviewer responded yes, key partners are represented. In some cases, key technology does reside outside the United States and there might be some need to explore when and at what level those key technical suppliers could be effectively engaged to bring their technology to the United States—like was done with Hitachi motors in the Kentucky plant, and Danfoss in New York, etc.

Reviewer 4:
The reviewer commented that, in general, the answer is yes, the program area has engaged appropriate partners, but more collaboration with industry and academia is needed. The more effective collaboration seems to be among the national laboratories.

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

Reviewer 1:
The reviewer stated yes, the program area is effectively collaborating with its partners.

Reviewer 2:
The reviewer thought the program was collaborating with partners effectively and noted that the key is manufacturing technology to commercialize the technology.

Reviewer 3:
The reviewer stated yes, the program area is collaborating with partners effectively.

Reviewer 4:
The reviewer noted that better collaboration with industry and academia is needed.

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

Reviewer 1:
The reviewer could not identify any gaps in the technology portfolio.

Reviewer 2:
The reviewer noted that the portfolio seems comprehensive and complete. One area that might require more attention is advanced manufacturing especially additive manufacturing for electric machines.

Reviewer 3:
The reviewer commented that methods for doubling component life (300,000 miles) for new mobility services could be a new addition to the portfolio.

Reviewer 4:
The reviewer indicated that it looked like the film capacitor has a larger gap in the portfolio.

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

Reviewer 1:
The reviewer noted that advanced manufacturing, especially additive manufacturing in electrical machines, could be more adequately addressed as well as more integrated systems and fully integrating the power electronics and electric machines.

Reviewer 2:
The reviewer commented that reliability, lifting, and sustainable manufacturing are topics that would benefit from increased attention.

Reviewer 3:
The reviewer stated that perhaps the need for power system and drive system safety architecture for autonomous vehicles could be more adequately addressed; in particular, the reviewer pointed out what kind of potential redundancy, safety and reliability is needed.

Reviewer 4:
The reviewer opined that thermal material could be more adequately addressed.

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

Reviewer 1:
The reviewer stated that advanced manufacturing, especially additive manufacturing in electrical machines and more integrated systems and fully integrating the power electronics and electric machines, should be considered for additional funding.

Reviewer 2:
The reviewer commented that system prognostics and non-destructive evaluation and testing technology are areas that would help promote the market penetration of cost-competitive electric vehicles should be considered for additional funding.

Reviewer 3:
The reviewer did not know of any areas that should receive additional funding.

Reviewer 4:
The reviewer stated that a higher voltage system (e.g., 800V) should receive additional funding.

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

Reviewer 1:
The reviewer stated that focusing more on advanced materials, advanced manufacturing and more integrated systems is a new way to approach barriers.

Reviewer 2:
The reviewer recommended the goal of avoiding rare-earths in motor technology given the current market conditions for commodities and specialty metals. While future supply shocks may always be a possibility, this reviewer indicated that there may be benefits in shifting focus away from reducing rare-earth content back towards increased performance.

Reviewer 3:
The reviewer had no suggestions.

Reviewer 4:
The reviewer had no suggestions.

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

Reviewer 1:
The reviewer recommended that the program continue the laboratory focus on materials and commercial original equipment manufacturer (OEM), and suppliers for component developments.

Reviewer 2:
The reviewer had no further suggestions.

Reviewer 3:
The reviewer had no other suggestions to make.

Reviewer 4:
The reviewer had no suggestions.

Project Feedback

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

Table 2-1 – Project Feedback

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
edt015	Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors	Iver Anderson (Ames Laboratory)	2-12	3.60	3.60	3.50	3.30	**3.55**
edt061	Cost-Effective Fabrication of High-Temperature Ceramic Capacitors for Power Inverters	Balu Balachandran (ANL)	2-16	3.50	3.50	3.67	3.50	**3.52**
edt067	High-Efficiency High-Density GaN-Based 6.6kW Bidirectional On-Board Charger for PEVs	Charles Zhu (Delta Products Corporation)	2-18	3.50	3.25	3.25	3.38	**3.33**
edt074	Non-Rare Earth Electric Motors	Tim Burress (ORNL)	2-21	3.29	3.14	3.00	3.00	**3.14**
edt075	Electric Motor Thermal Management	Kevin Bennion (NREL)	2-27	3.08	3.25	3.25	3.00	**3.18**
edt076	Electric Drive Inverters	Madhu Chinthavali (ORNL)	2-32	3.00	2.75	3.00	2.75	**2.84**
edt077	Wireless Power Transfer Integrated Chargers	Veda Galigekere (ORNL)	2-34	3.00	2.88	2.75	3.00	**2.91**
edt078	Power Electronics Thermal Management	Gilbert Moreno (NREL)	2-37	2.67	2.83	3.50	2.67	**2.85**
edt079	Materials for Advanced Packaging	Andy Weresczack (ORNL)	2-40	3.13	3.00	3.25	3.13	**3.08**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
edt080	Performance and Reliability of Bonded Interfaces for High-Temperature Packaging	Paul Paret (NREL)	2-43	3.25	3.00	3.25	3.25	**3.13**
edt081	Multilayered Film Capacitors for Advanced Power Electronics and Electric Motors for Electric Traction Drives	Deepak Langhe (Polymer Plus)	2-45	3.50	3.33	3.33	3.33	**3.38**
edt082	Highly Integrated Wide Bandgap Power Module for Next Generation Plug-In Vehicles	Brian Peaslee (General Motors)	2-47	3.25	3.13	3.00	3.38	**3.17**
edt083	650V SiC Integrated Power Module for Automotive Inverters	Monty Hayes (Delphi Automotive Systems, LLC)	2-51	3.00	2.88	3.00	2.88	**2.92**
edt087	Electrical Performance, Reliability Analysis, and Characterization	Tim Burress (ORNL)	2-54	3.30	3.20	3.20	3.20	**3.23**
Overall Average				**3.23**	**3.15**	**3.20**	**3.11**	**3.17**

Presentation Number: edt015
Presentation Title: Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors
Principal Investigator: Iver Anderson (Ames Laboratory)

Presenter
Iver Anderson, Ames Laboratory

Reviewer Sample Size
A total of five reviewers evaluated this project

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

Reviewer 1:
The reviewer remarked the approach for this project is to develop comprehensive models for the magnetic behavior of materials, which drive the specific processing steps in the fabrication process. This is a great approach, as it leads to a greater understanding about which steps lead to different characteristics. An example was given in the presentation about how the modelling approach saved time and effort when investigating the effects of adding nickel.

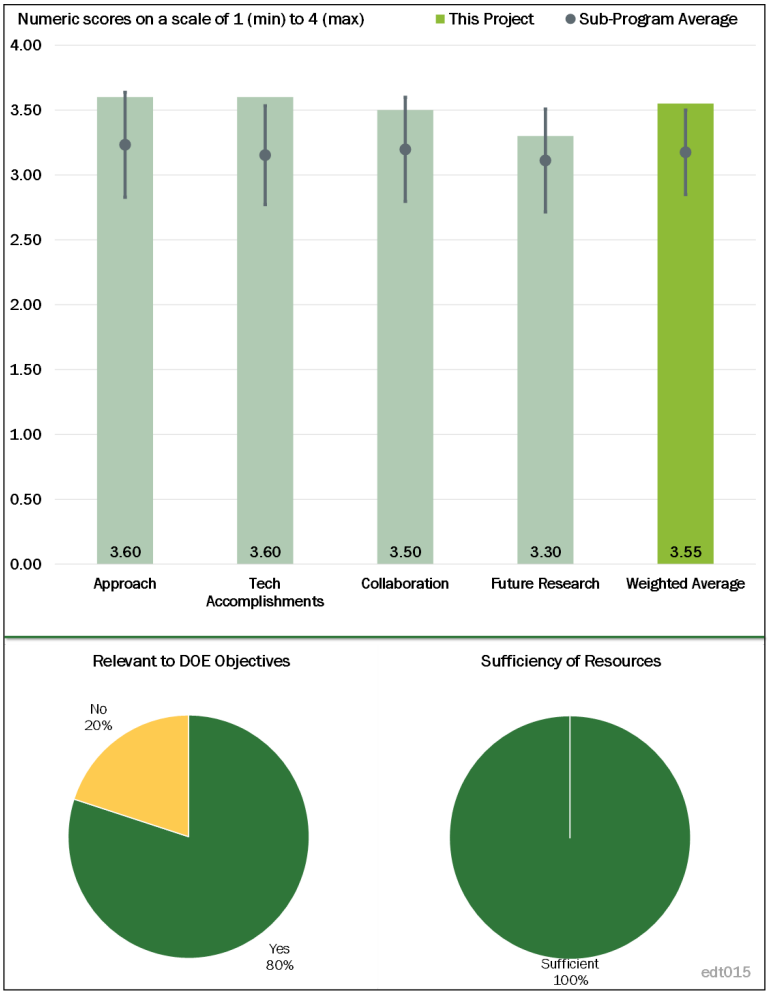

Figure 2-1 - Presentation Number: edt015 Presentation Title: Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors Principal Investigator: Iver Anderson (Ames Laboratory)

Reviewer 2:
The reviewer said that the project approach dives into the physics and material properties of the targeted and new magnetic materials. The approach is very systematic, and feasible.

Reviewer 3:
The reviewer remarked that the investigator has clearly laid out near-term and long-term non-rare-earth (RE) magnet development work with how a super aluminum-nickel-cobalt-(AlNiCo) magnet will be realized.

Reviewer 4:
The reviewer observed a very systematic approach.

Reviewer 5:
The approach is quite nice and good performance has been achieved. The reviewer would like to see an approach slide that discusses various aspects of the problem and challenges of the non-RE magnets.

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

Reviewer 1:
The reviewer remarked the project is making quantifiable progress across the spectrum.

Reviewer 2:
The reviewer remarked that the project is making great strides to understand at a material level what is happening with the magnetic materials. The formation process, and certain processes that cause variation, will help manufacturers make higher quality magnets. The project completed bulk magnets in March, but did not present magnetic properties yet. This reviewer noted that some sort of physical testing is needed, for a go/no go decision, before moving on to the next iteration.

Reviewer 3:
The reviewer believed the authors are making good progress towards the DOE goal. One thing the reviewer would like to see is the cost target for these magnets and whether they can be achieved in the near-term.

Reviewer 4:
The reviewer observed the team varied the magnet composition in order to determine the tradeoffs among saturation, remanence, coercivity, and energy product, leading to optimization of the magnet. The magnet's coercivity was 8% higher than the previous year, though the other major parameters decreased. However, the team has a plan in place to further optimize the magnet.

Reviewer 5:
The reviewer said apart from conducting basic research related to non-RE magnets for electric motors, the DOE VTO should encourage the investigator to collaborate either with industry or a university, and the project must build an electric machine that could be driven by inverter. This will allow the investigator to see how super-AlNiCo performs in an inverter-fed application, including any abnormal operating conditions of an inverter, such as an unsymmetrical fault in the inverter.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that this project has a very good team. It covers research laboratories, magnet manufacturers, motor manufacturers and vehicle OEMs.

Reviewer 2:
The reviewer noted that the team is collaborating with several academic and industrial partners to develop technical targets for the program.

Reviewer 3:
The reviewer remarked that university, industry, and DOE-laboratory collaboration exists in this project.

Reviewer 4:
The reviewer commended the amount of engagement on this project, but a way must be found to have regular discussion with OEMs on their magnet needs/types.

Reviewer 5:
The reviewer suggested that the group start making progress towards building a prototype by involving OEM Tier 1 suppliers.

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

Reviewer 1:
The reviewer said that the planning seems logical as a next step.

Reviewer 2:
The reviewer commented the project has a good plan for future research, where the theoretical models will be expanded and improved and the magnet fabrication process will be further optimized.

Reviewer 3:
According to the reviewer, the project has good overall goals listed, but is lacking milestones to gauge progress. The project had relevant risks listed, but there were not any alternative development pathways presented for mitigating risk.

Reviewer 4:
The reviewer remarked it would be desirable if test samples are used for electric motor fabrication.

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

Reviewer 1:
The reviewer commented that the magnets being developed in this project are an enabling technology, supporting the manufacture of lower cost electric motors. Electric motors have been proven to reduce petroleum use in hybridized vehicles.

Reviewer 2:
The reviewer commented the project supports DOE objectives by developing a low-cost motor for electrified vehicles.

Reviewer 3:
The reviewer said that this project develops new magnet materials that can replace RE magnets, thus eliminating or reducing exposure to the highly volatile RE magnet market.

Reviewer 4:
This reviewer did not hear the investigator talking about how his research will impact DOE's petroleum displacement objective. The reviewer said if using super-AlNiCo allows to shrink the size of an electric motor while lowering its weight yet keeping high-efficiency operation intact over the temperature, it can be justified that the proposed research would meet DOE's objective for petroleum replacement.

Reviewer 5:
This reviewer's only concern is that market dynamics change quicker than the research direction can to answer a specific question. Understanding fundamentals or basic science seems to be the best way for a project to stay relevant if it is followed up by educating industry with findings.

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

Reviewer 1:
The reviewer commented the resources are sufficient and a good team of national laboratories is formed to tackle the challenges.

Reviewer 2:
The reviewer said the resources appear to be appropriate for the project.

Reviewer 3:
The reviewer said the investigator did not mention that resources were lacking.

Reviewer 4:
The reviewer said that the project research is progressing well with the resources. It appears the project is on track, but the reviewer pointed out there is a lack of milestones to compare against.

Presentation Number: edt061
Presentation Title: Cost-Effective Fabrication of High-Temperature Ceramic Capacitors for Power Inverters
Principal Investigator: Balu Balachandran (Argonne National Laboratory)

Presenter
Balu Balachandran, Argonne National Laboratory

Reviewer Sample Size
A total of three reviewers evaluated this project

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

Reviewer 1:
The reviewer remarked that the planned and executed testing under real-application conditions is well thought out.

Reviewer 2:
The reviewer said that this seems to be a good approach to produce low-cost, high-temperature capacitors. The higher temperature rating of these capacitors will allow size reduction of the inverter system.

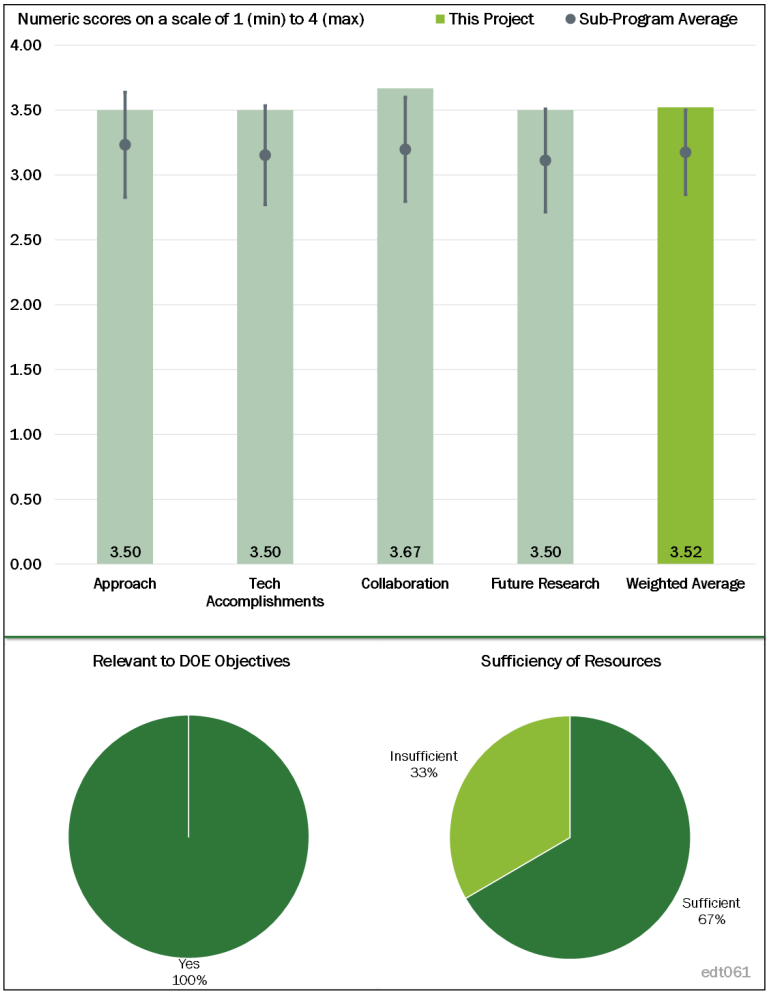

Figure 2-2 - Presentation Number: edt061 Presentation Title: Cost-Effective Fabrication of High-Temperature Ceramic Capacitors for Power Inverters Principal Investigator: Balu Balachandran (Argonne National Laboratory)

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

Reviewer 1:
The reviewer said that the capacitors appear to perform well and the team is making good progress on scaling up the system for larger components.

Reviewer 2:
The reviewer commented that accomplishments have been substantial, but this reviewer would have liked to see a faster pace of work than it has been over the years.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented that the team partnered with Delphi to determine technical specifications, Sigma Technologies for developing a large-scale fabrication process, and Penn State University for characterization and testing. The reviewer found that this seems to be a good combination for the work.

Reviewer 2:
This reviewer would like to see direct OEM involvement.

Reviewer 3:
The reviewer noted a great diversity of experience, integration, and contribution in the value chain.

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

No comments were received in response to this question.

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

Reviewer 1:
The reviewer pointed out that low-cost, high-temperature capacitors are critical to meeting the size and cost targets of inverter systems.

Reviewer 2:
The reviewer said that the project definitely addresses a key element of what is needed as industry moves to WBG-based power electronics.

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 the funding level slowed this work.

Reviewer 2:
The reviewer said that the resources for this project appear to be sufficient.

Presentation Number: edt067
Presentation Title: High-Efficiency High-Density GaN-Based 6.6kW Bidirectional On-Board Charger for PEVs
Principal Investigator: Charles Zhu (Delta Products Corporation)

Presenter
Charles Zhu, Delta Products Corporation

Reviewer Sample Size
A total of four reviewers evaluated this project

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

Reviewer 1:
The reviewer commented that the approach is technically sound, and has produced promising results.

Reviewer 2:
The reviewer commented that the investigator has tested three generations of gallium nitride (GaN) metal-oxide-semiconductor field-effect transistor (MOSFETs) while developing a high-efficiency on-board charger for plug-in electric vehicles (PEVs) and then he decided the best GaN MOSFET that works in his applications rather than selection based on lowest Rds(on). The investigator approach that a bi-directional on-board charger could allow PEVs to work as emergency power source, particularly in an area affected by natural disaster, could be very appealing to early adopters of electric cars.

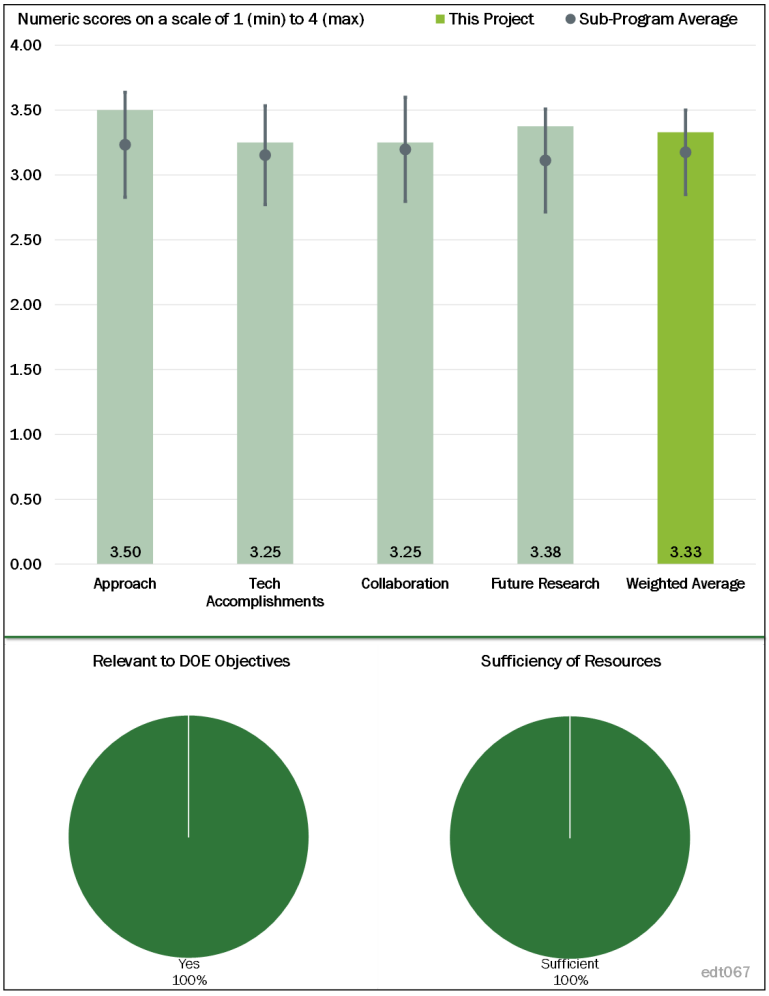

Figure 2-3 - Presentation Number: edt067 Presentation Title: High-Efficiency High-Density GaN-Based 6.6kW Bidirectional On-Board Charger for PEVs Principal Investigator: Charles Zhu (Delta Products Corporation)

Reviewer 3:
The reviewer commented that a basic approach is laid out to address the objectives. Other than building A and B samples with GaN, it is unclear to this reviewer how or what will accomplish Delta's end goals.

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

Reviewer 1:
The reviewer commented that progress has been very good, and demonstration testing has gone extremely well.

Reviewer 2:
The reviewer detailed that a prototype charger was fabricated and tested with a 30° Celsius (C) coolant to extrapolate data for higher temperature coolant. Efficiency was measured and found to be 95% at 50% output, which could be the case for most of the time for the proposed on-board charger while handling power flow in either redirection.

Reviewer 3:
The reviewer said that progress on hardware was excellent, and this reviewer would like to see more data.

Reviewer 4:
The reviewer observed good progress and learnings, overall. The reviewer had some concern that B-samples are falling well short of ambient design intent specifications and that no attempt has been made at conducting an electromagnetic compatibility (EMC) survey, knowing that EMC is a concern when pushing higher switch speeds with WBG semiconductors, and that while the semi's temperatures are good, other active and passive components in a WBG power conversion system may prove to be a challenge.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that working directly with the device manufacturer and an OEM is exactly the correct path for this project.

Reviewer 2:
The reviewer observed a solid team with wide participation.

Reviewer 3:
The reviewer noted that university/industry collaboration exists in the project. The converter topology proposed by the Virginia Tech University Center for Power Electronics Systems is completely different than converter topology developed by Delta, therefore, it is difficult to assess how effective collaborative activity could be for this project.

Reviewer 4:
The reviewer observed good collaboration with industry and academia. The reviewer would have liked to have seen the National Renewable Energy Laboratory (NREL) contributing to thermal work, and/or Oak Ridge National Laboratory (ORNL) contributing to power conversion, as a team member to round out the team's 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 said that size reduction and improved thermal performance are critical to production application. Delta has a solid plan for this in future testing/development.

Reviewer 2:
The reviewer remarked that the commercialization plan is stated in the project report, and this should help meet DOE's "Technology to Market" goal. Also, the reviewer pointed out that the investigator has stated how he plans to improve developed technology, which should support his objectives towards commercialization plans for developed technology despite the excessively high price of GaN MOSFETs.

Reviewer 3:
The reviewer said these are good, natural, next steps in development, but not necessarily research.

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

Reviewer 1:
The reviewer pointed out that lower cost, high-performance and smaller volume chargers that can operate at higher voltages are critical to mass adoption to electric drive technologies (EDTs).

Reviewer 2:
The reviewer commented that exploring this application of WBG along with new features for the consumers are relevant to the program.

Reviewer 3:
The reviewer said that demonstration by testing high efficiency should allow energy savings; however, the project report does not quantify the petroleum displacement potential due to introduction and mass adoption of the GaN MOSFET-based on-board charger for PEVs.

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

Reviewer 1:
The reviewer noted that Delta has adequate resources for this project. On vehicle testing, it will be critical to finalize this project.

Reviewer 2:
The reviewer said the investigator did not mention a lack of resources.

Presentation Number: edt074
Presentation Title: Non-Rare Earth Electric Motors
Principal Investigator: Tim Burress (Oak Ridge National Laboratory)

Presenter
Tim Burress, Oak Ridge National Laboratory

Reviewer Sample Size
A total of seven reviewers evaluated this project

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

Reviewer 1:
The reviewer said that the project approach of working on modeling, materials, and prototype design/build for validation is a good approach. This project focused on a commercial motor footprint (Prius motor) as a form factor. The reviewer said it is feasible that the improved motor could be integrated into a vehicle such as the Prius for comparative testing in a future program.

Reviewer 2:
The reviewer said that the technical challenges are addressed through modeling and fits well with fundamental work on non-RE magnets in Ames.

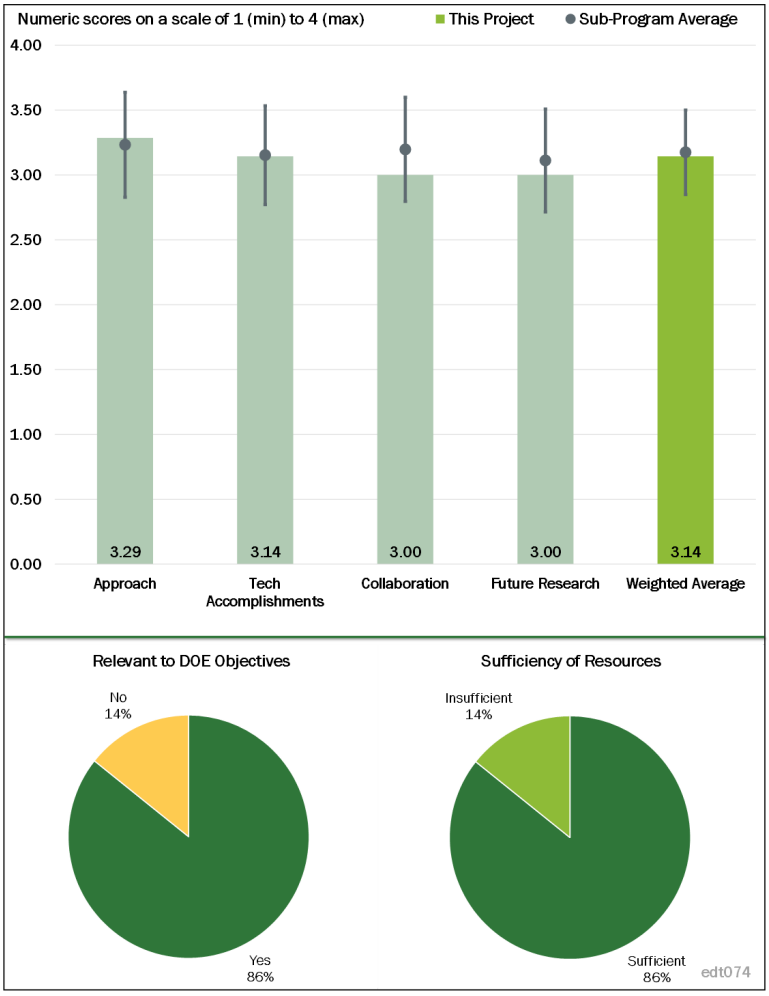

Figure 2-4 - Presentation Number: edt074 Presentation Title: Non-Rare Earth Electric Motors Principal Investigator: Tim Burress (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer summarized that the approach is a broad-based approach toward addressing both the system and material level issues facing the development of non-RE containing motors. A robust system design effort has led to the demonstration of a high-power, non-RE containing motor. This prototype development effort was supported by component modeling and characterization efforts that included modeling the loss mechanisms in soft magnetic materials, investigating high-silicon (Si) content steel manufacturing, and investigating high-conductivity carbon nanotube (CNT)/copper (Cu) matrix composites.

The reviewer noted that there appears to be an effective allocation of resources among the various development tasks. The machine design and component characterization tasks are feasible and are integrated with other efforts that provide relevant data, such as thermal conductivity of components such as windings. According to the reviewer, the CNT/Cu conductor development, high-Si steel development, and soft magnetic material modeling are longer-term, higher risk efforts that will face challenges but are potentially transformational.

Reviewer 4:
The reviewer said this is a very good approach to developing new motor technologies that do not depend on RE magnet materials. New core and winding materials are being developed to improve power density and efficiency. Additionally, advanced modelling methods are being developed that will aid the design process.

Reviewer 5:
The reviewer commented that the project covers a broad range of topics, and several of them can have a very significant impact on motor technologies moving forward. The reviewer suggested picking the one or at most two most-promising technologies and focus on further developing them and scaling them up to the point that full-scale motors can be built. The reviewer's opinion is that CNT/Cu conductors should be a focus area.

Reviewer 6:
The reviewer commented that an advanced modeling tool will allow investigators to get a motor model well before a physical machine is built. This will help mitigate any risks, such as needs for unnecessary revisions. If the developed motor model and its parameters are used for some advanced simulation tools (e.g., hardware-in-the-loop), the reviewer recommended simulation to assess how the motor could perform when driven by the inverter.

Reviewer 7:
The reviewer said that the fundamental approach of performing fundamental research to improve motor modeling accuracy first is good. The reviewer pointed out that thermal transfer in windings is good work; however, as seen from Toyota benchmarking by ORNL, and by Bosch, Denso, and General Motors' (GM) applications, bar windings are becoming the leading technique for more effective heat transfer. There is now a baseline to compare improved heat transfer with bar versus fly winding.

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

Reviewer 1:
The reviewer commented that it seems like the investigators are carrying out basic research, which looks great. This reviewer suggested that investigators should explore issues related to the application of the proposed machine. One such example is looking into demagnetization that could occur if the inverter-fed electric machine system experiences unsymmetrical faults in the inverter hardware, which could result in significant direct current (DC) current flow through stator windings.

Reviewer 2:
The reviewer commented that the modeling efforts are building on previous work to increase accuracy and the computational domain. The project investigated thermal characteristics of motor windings, along with an ultra-conductive Cu technology that incorporates CNT into a Cu matrix. The reviewer observed that the project developed new processing methods for low-loss ferrosilicon (FeSi) core materials and completed a motor design.

Reviewer 3:
The project has made noteworthy progress in designing and demonstrating a RE-free motor that exceeds the power and power density targets of the DOE's 2022 EV roadmap. It is not clear if the motor prototypes also meet the efficiency targets over the entire range of speed and power. The reviewer commented that reliability was not addressed. The series/parallel synchronous reluctance (SynchRel) concept is intriguing and opens up regions of performance for completely magnet-free SynchRel machine designs that may not have been addressed before. However, according to the reviewer, the impact of the series/parallel scheme on the complexity and cost of the power electronics and the motor controller was not discussed.

The other technology efforts are longer-term R&D efforts that are critical to long-term competitiveness, but their link to meeting the 2022 targets are not as well defined. The reviewer commented that it is intuitively

apparent that an improved ability to model the magnetization processes in soft magnetic materials, based on micromagnetic approaches that are supported by atomistic simulations, should lead to improved motor designs. However, it may not be possible to quantify the degree of expected improvement at this time. The reviewer said that without this information, it is then also not possible to compare the benefit of the simulation approach to the cost of the computational methods needed to realize it. Future work in this space should focus on building transfer functions that connect system level performance metrics to design and microstructure parameters that are used in the computational framework.

Reviewer 4:
The reviewer said that proving the feasibility of a reconfigurable-winding SynchRel machine (six switches) needs technical assessments from power switch packaging, thermal, and motor control parameter changes "on-the-fly"—then compare this to a two-speed gearbox.

Reviewer 5:
The reviewer said that the progress so far is okay but difficult to judge due to lack of quantifiable targets. The reviewer remarked that the authors need to state the targets clearly.

Reviewer 6:
The reviewer pointed out that it would have been helpful if the actual DOE goals were listed side by side with the program metrics, but in the presentation and oral presentation, it was validated that the cost and volume targets were being met. The project is on track with the quarterly milestones. The reviewer said that manufacturing and processing new materials are being worked through as a potential further performance improvement.

Reviewer 7:
The reviewer detailed that a lot of good work has been done but in some cases the outcome might not be very clear, and gave as an example the case of advanced materials modeling at the grain level.

According to this reviewer, it was mentioned that a ferrite motor can accomplish significantly more power within the same volume compared to an interior permanent magnet motor. The reviewer asked how this was accomplished, and asked if a thorough demagnetization analysis/testing especially at very low temperatures was performed.

The concept of a synchronous reluctance machine with reconfigurable windings has been presented. The reviewer noted that the concept of reconfigurable windings has been proposed in literature a long time ago, especially for induction machines. It was never widely adopted due to additional cost and reliability concerns due to the additional circuitry needed. The reviewer said that some comments/discussions about this point should be included.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted strong collaboration exists among ORNL; NREL; University of Wisconsin, Madison; and BorgWarner. These collaborative activities will help investigators solve application related issues.

Reviewer 2:
The reviewer noted that collaborations with Wisconsin, NREL, and Ames appear to be well coordinated and are adding value to the project.

Reviewer 3:
The reviewer commented that it seems there is good collaboration between the different groups within ORNL as well as between ORNL and other national laboratories. The level of collaboration with industrial partners or universities was not very clear.

Reviewer 4:
The reviewer commented that the project has strong collaboration with academia and other labs. The team is coordinating with other projects such as Development of Radically Enhanced AlNiCo Magnets (DREaM) to keep alternative motor design options open. The reviewer remarked that it would have been a stronger collaboration if there was a motor manufacturer as part of the team.

Reviewer 5:
The reviewer said that the team partnered with the University of Wisconsin to aid the motor design and finite element analysis studies. NREL will provide feedback on motor cooling techniques and the team is involved with the DREaM project at Ames. The reviewer would like to see an industry partner here to ensure that the technologies will have a commercialization path.

Reviewer 6:
The reviewer said that the authors need to coordinate with an OEM to understand the requirements of the new magnets and guide research accordingly.

Reviewer 7:
The reviewer said that there seems to be little evidence presented on which partners performed what work on the project. Contributions from the University of Wisconsin, NREL and Ames are noted, but it was not clear what work was performed. The reviewer did not see contributions from BorgWarner.

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

Reviewer 1:
The reviewer said that the team has a good plan for continuing development of their advanced materials, modeling methods, and motor prototypes.

Reviewer 2:
The reviewer commented that the investigator plans to build a prototype.

Reviewer 3:
The reviewer said the goal of building and testing a full scale motor would be very valuable. The key challenge is which areas to focus on and which technologies/learnings would go into this prototype. The reviewer commented this was not very clear.

Reviewer 4:
The reviewer said that the proposed future research is to move to an optimized design based on the phase on results (and experimental findings). There are a few alternative options being followed (and developed) to help mitigate risk, and potentially advance motor designs. The reviewer noted that the project had a couple material-related challenges listed, which were good to track. The project missed a couple of major challenges (torque ripple and acoustic noise) that would need mitigation to enable commercial (and end consumer) acceptance of the SynchRel motor being prototyped.

Reviewer 5:
The proposed future research has parallel tasks centered on numerical and experimental studies of magnetic materials, conductor materials, and advanced electric motors. The go/no-go decision point of having a design projected to meet DOE's 2020 motor targets is appropriate. The reviewer said the team may wish to clarify if these are year 2020 or year 2022 motor targets.

Reviewer 6:
The reviewer said that in addition to using results from evaluation and materials research to design, build, and test the prototype, the feasibility of using CNT and the high-Si lamination in the motor design needs to be addressed.

Reviewer 7:
The reviewer commented that the authors need to state the targets clearly, which are currently missing and therefore not able to judge any risks that can be anticipated.

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

Reviewer 1:
The reviewer said that it does in reducing dependence on RE magnets.

Reviewer 2:
The reviewer remarked that low-cost non-RE motor solutions are relevant.

Reviewer 3:
The reviewer commented that this project focuses on the important strategic area of reducing RE magnetic materials. This can have a significant impact on sustainability and the cost of traction motors moving forward.

Reviewer 4:
The reviewer pointed out that making a better electric motor would help accelerate hybridization of vehicles, which has been proven to reduce the amount of petroleum required. The new materials being investigated and how to process them for manufacturing has the potential to be a technology leap moment.

Reviewer 5:
The reviewer detailed that the fundamental understanding of magnetic materials imparted by the advanced modeling task may accelerate the introduction of higher performance magnetic materials enabling increased motor efficiency. The development of a non-RE containing motor will increase the sustainability of the supply chain that supports electric vehicle manufacturing. These effects would have the effects of increasing market penetration of higher efficiency EVs, reducing the demand for petroleum in the transportation sector.

Reviewer 6:
The reviewer said this project seeks to develop motor technologies that avoid the market risk associated with RE magnetic materials while maintaining high power density and efficiency.

Reviewer 7:
The reviewer commented that this was not discussed in the project report and during oral presentation.

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

Reviewer 1:
The reviewer said that based on the scope, it seems that allocated funding should be sufficient.

Reviewer 2:
The reviewer commented that the team is progressing in a timely manner.

Reviewer 3:
The reviewer said that the project budget seems appropriate for the level of effort that is in the project scope.

Reviewer 4:
The reviewer found that resources for this project appear to be sufficient.

Reviewer 5:
The reviewer said that the investigator did not mention that resources are lacking.

Reviewer 6:
The reviewer commented that at some point the labs need to engage an OEM and work toward a prototype magnet. This needs to be addressed while planning research.

Reviewer 7:
The reviewer said that it seems the many technical challenges to fabricating and processing FeSi motor laminations and ultra-conductive Cu will require more resources.

Presentation Number: edt075
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 six reviewers evaluated this project

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

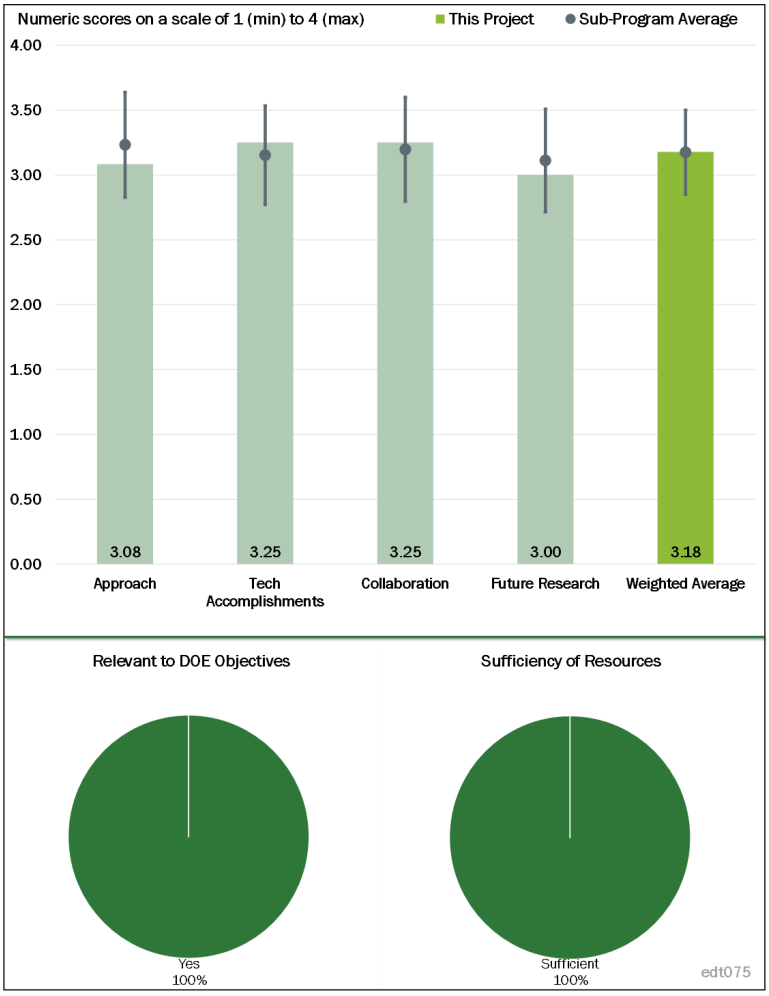

Figure 2-5 - Presentation Number: edt075 Presentation Title: Electric Motor Thermal Management Principal Investigator: Kevin Bennion (National Renewable Energy Laboratory)

Reviewer 1:
The reviewer detailed that the project attempts to experimentally quantify various aspects of thermal management for electric motors. It will become more valuable once these results feed into an electric motor design process and the motor thermal performance is experimentally verified.

Reviewer 2:
The reviewer said that the project has completed a well-designed down-selection method choosing the most appropriate thermal management technologies, and identified the most important material property data that are needed to enable those technologies. Experimental data has been used to validate thermal models using multiple materials. The project is well integrated with motor design efforts at ORNL. The reviewer noted that the interaction with Ames is generating needed data on both the thermal and mechanical properties of AlNiCo permanent magnets.

Reviewer 3:
The reviewer said that this work focuses on performing thermal measurements on motors and developing detailed thermal models. The project will characterize materials and investigate different cooling methods.

Reviewer 4:
The project is focused on motor cooling and is well integrated with other DOE projects. The reviewer prefers providing a strong motivation for the study compared to a traditional approach and the gains in terms of pumping power or performance.

Reviewer 5:
The reviewer said that active cooling of the electric machine will allow size reduction and will improve peak load capability. However, cost and complexity due to active cooling system should be justifiable for a given application.

Reviewer 6:
The project is addressing barriers as they come along, and that they are not laid out. The project is feasible, and supporting others, but less structured then a stand-alone program.

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

Reviewer 1:
The reviewer said that the team has made good progress on measuring the thermal properties of direct impingement and passive cooling methods. The team has also performed transverse rupture strength and thermal conductivity characterization of the Ames magnet material, along with two AlNiCo comparables.

Reviewer 2:
The reviewer said that the established test setups as well as the experimental results are very useful. Once they feed into an actual motor design process and the motor thermal performance is verified, this work will become even more valuable. The reviewer also commented that the project needs to focus more on quantifying the impact of different insulation materials on the motor's thermal performance, and the long-term/life impact of spray cooling on the insulation system needs to be quantified.

Reviewer 3:
The reviewer found that the project is enabling other projects such as non-RE and DREaM to advance. Thermal management is one of the large barriers to increasing power density in electric motor and power electronics, which enable hybridization and meeting DOE's goals.

Reviewer 4:
The reviewer said that the project has made excellent progress in selecting appropriate thermal technologies, constructing thermal models, and collecting the experimental data needed to validate those models. The availability of the models and data will accelerate the development of energy-efficient EV motors.

Reviewer 5:
The reviewer commented that based on the presentation, the project seems to be on track.

Reviewer 6:
The reviewer commented that basic research work completed including characterization and testing at ORNL and Ames Laboratory.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed good collaboration with other national laboratories as well as industrial partners.

Reviewer 2:
The reviewer said the project is well-coordinated with the motor design effort at ORNL and the AlNiCo development at Ames. The project is sharing appropriate models and data with industry participants.

Reviewer 3:
The reviewer said that collaboration and coordination seems adequate for the project.

Reviewer 4:
The reviewer commented that the main effort described is supporting other projects and institutions. After the modeling is completed, there may be more opportunities for collaboration with academia and motor manufacturers.

Reviewer 5:
The reviewer pointed out that the investigator proactively seeks inputs from the motor industry, which will be extremely valuable for technology transfer from NREL to U.S. industries.

Reviewer 6:
The reviewer said that thermal measurements and models support motor research at ORNL, and the material characterization work supports magnet research at Ames.

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

Reviewer 1:
The reviewer said that the project is focused on extending the model development to system components that more closely represent production designs. This work should be prioritized to accelerate introduction of advanced electric motor designs. The work on new materials is generating valuable data useful for the development of RE-free permanent magnets.

Reviewer 2:
The reviewer commented that the team has a clear plan for future research.

Reviewer 3:
The reviewer said that motor technology that exploits the benefits of WBG devices is needed and the investigator plans to explore insulation systems needed to sustain higher dv/dt and over-voltage caused by fast-switching of a SiC inverter.

Reviewer 4:
The reviewer said that in general, the proposed work is good. The reviewer referenced previous suggestions to build and test a motor prototype to verify the results; investigate impact of different insulation systems; and investigate the long-term/life impact of spray cooling on an insulation system.

Reviewer 5:
The reviewer said that the project seems to be doing good work supporting other projects, but does not appear to be a stand-alone effort. The project described supporting a non-RE project, and Ames-led magnet development. The project goes until 2019, but milestones or goals past September 2017 are not listed. The reviewer pointed out that barriers, risks, and alternative pathways were not listed.

Reviewer 6:
The reviewer said that the planning of the future work was to test non-RE magnets but the challenges associated with the new magnets was not clearly presented. The work seems a repeat of the past without demonstrating any novelty.

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

Reviewer 1:
The reviewer said that determining the optimal cooling methods for motor windings should lead to higher power density and/or a longer lifetime of the motors. The characterization work supports development of new magnetic materials, which will reduce exposure to the volatile RE magnet market.

Reviewer 2:
The reviewer said that thermal management is a key technology area that enables meeting performance metrics of traction motors and hence meeting the overall electric drivetrain performance targets.

Reviewer 3:
The reviewer commented that this project is a supporting effort for other projects, enabling them to increase petroleum displacement. Thermal management is one of the larger challenges to shrinking down the physical footprint of power electronics and motors, and this work could help enable those more power dense packages.

Reviewer 4:
The reviewer remarked that this project is providing thermal models and data that may accelerate the introduction of energy efficient electric motors. This may increase the market penetration of EVs, leading to the reduction of petroleum consumed in the transportation sector.

Reviewer 5:
The reviewer detailed that active cooling of an inverter-fed electric motor will shrink the size and reduce the weight of an electric machine, which could make electric drivetrains lighter. Light-weight vehicles are going to consume less fuel. However, according to the reviewer the investigator did not quantify petroleum displacement data. The reviewer encouraged the investigator to quantify by using a baseline example of how the active cooling proposed will reduce the size and weight of an electric motor, thereby resulting in fuel savings.

Reviewer 6:
The reviewer said the project supports potential use of non-RE magnets, and this project does not support petroleum displacement.

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

Reviewer 1:
The reviewer said that project resources seem sufficient for the scope of work.

Reviewer 2:
The reviewer said that based on the scope, the funding level seems sufficient.

Reviewer 3:
The reviewer pointed out that the project did not define milestones very far out (only until September 2017). As these are in progress, there appears to be sufficient resources.

Reviewer 4:
The reviewer found that resources for this project appear to be sufficient.

Reviewer 5:
The reviewer commented that the investigator did not mention that resources are lacking.

Reviewer 6:

The reviewer said that resources are more than sufficient for the project.

Presentation Number: edt076
Presentation Title: Electric Drive Inverters
Principal Investigator: Madhu Chinthavali (Oak Ridge National Laboratory)

Presenter
Madhu Chinthavali, Oak Ridge National Laboratory

Reviewer Sample Size
A total of two reviewers evaluated this project

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

Reviewer 1:
The reviewer commented that the project should not need to develop a short circuit test circuit for capability evaluation. A standard test circuit from previous work should be sufficient. The reviewer agreed that a low-parasitic package at high di/dt operation is needed, and pointed out that a traction inverter topology that includes a series-integrated buck/boost converter cannot be assumed in most cases. The reviewer noted that this approach adds series conversion losses for the benefit of integrating a wired charger, which adds powered time to inverter standby mode and adds potential failure modes while on plug.

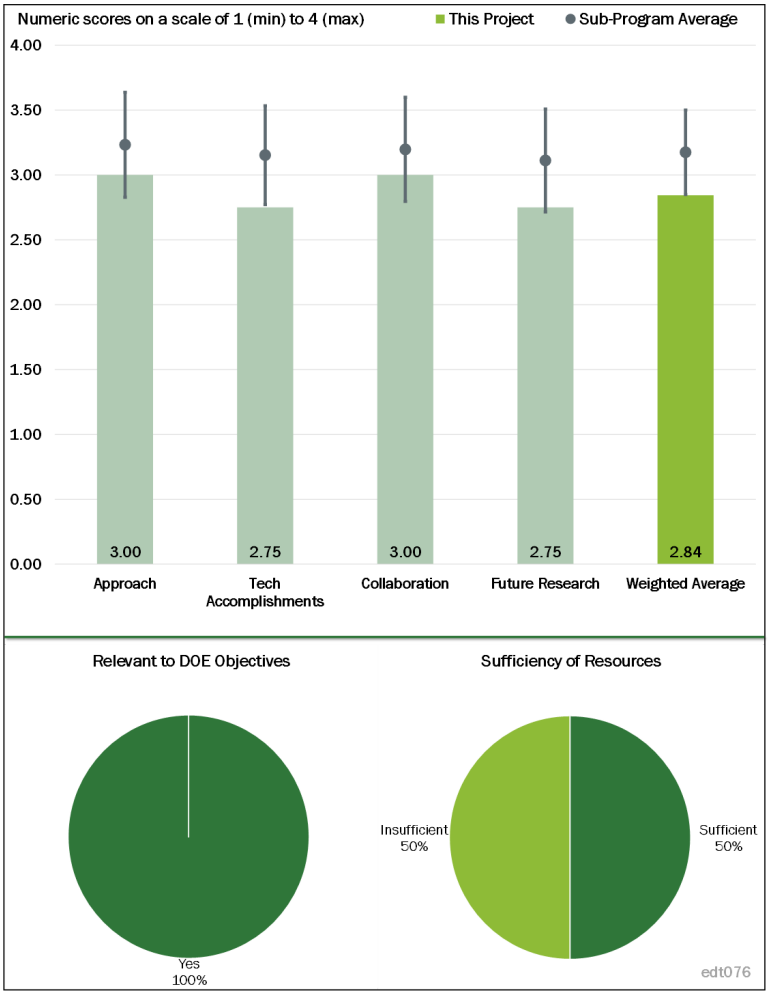

Figure 2-6 - Presentation Number: edt076 Presentation Title: Electric Drive Inverters Principal Investigator: Madhu Chinthavali (Oak Ridge National Laboratory)

Reviewer 2:
The reviewer noted that there are three tasks planned, Tasks 2, 3 and 4. The reviewer said that the scope might be too big; there is a risk to do all three. The reviewer suggested focusing on one task and doing it more thoroughly.

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

Reviewer 1:
The reviewer said that progress is satisfactory towards the overall concept selected.

Reviewer 2:
The reviewer said that this is the first year of the program, and so far it is on a good track.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed a good team.

Reviewer 2:
The reviewer was unclear what collaboration was performed by SBE, ROHM, Cree, and REMTEC, other than providing parts.

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

Reviewer 1:
The reviewer said that the gate drive techniques to improve the light load efficiency is of marginal benefit, given the remarkably low E_on and E_off of SiC MOSFETs. Operation without anti-parallel SiC Schottky barrier diodes (SBD) has been previously proven to be viable.

Reviewer 2:
The reviewer said that high power efficiency needs to be considered as well.

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

Reviewer 1:
The reviewer said that certainly improving efficiency supports this goal.

Reviewer 2:
The reviewer noted novel circuit technology with advanced packaging to reduce cost, improve efficiency and reliability, and increase power density of traction drive system for EVs.

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

Reviewer 1:
The reviewer said that team composition seems adequate with funding level.

Reviewer 2:
The reviewer said that three hardware (Task 2, 3, and 4) evaluations is too much, and the reviewer suggested focusing on only one.

Presentation Number: edt077
Presentation Title: Wireless Power Transfer Integrated 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, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer observed a sound approach, and that alternatives were considered and evaluated.

Reviewer 2:
The reviewer commented that to save the voltage regulator stage by sharing the boost converter in the traction inverter electronics is a cost-saving approach.

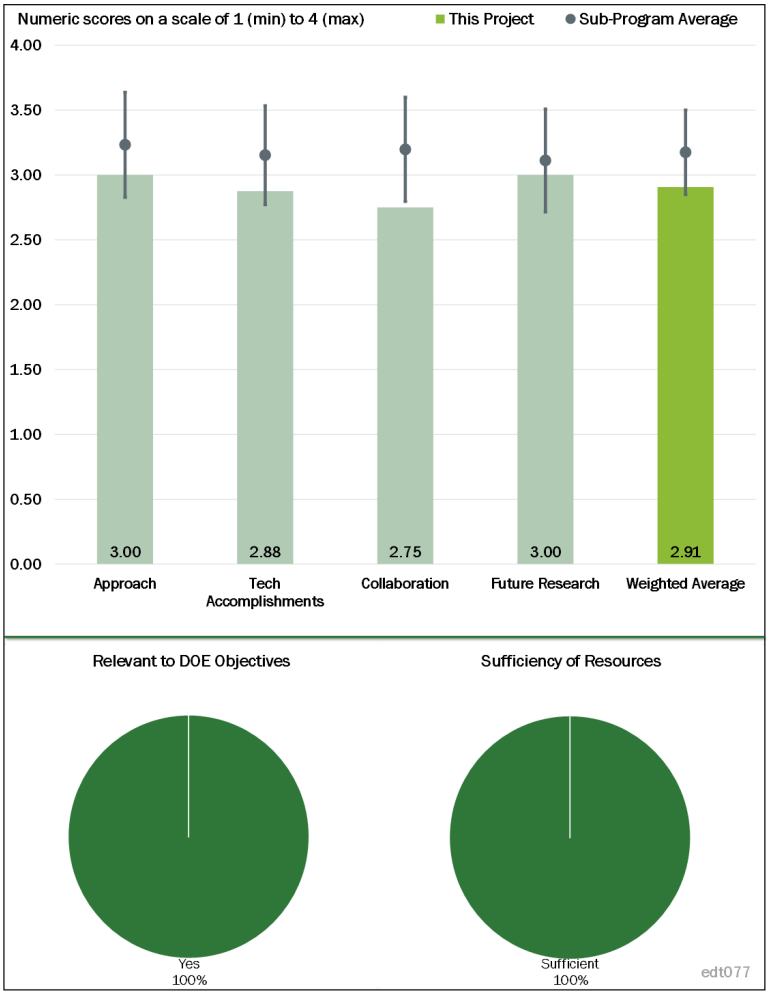

Figure 2-7 - Presentation Number: edt077 Presentation Title: Wireless Power Transfer Integrated Chargers Principal Investigator: Veda Galigekere (Oak Ridge National Laboratory)

Reviewer 3:
The reviewer said that the lifetime for the integrated DC-DC converter due to increased use of the boost converter is listed as one of the two technical barriers. The reviewer was not clear why the increased use of the boost converter is a technical barrier. The reviewer remarked that the project is well-designed; however, it is not clear that how this project is integrated with other efforts. Several ORNL researchers as well as NREL were mentioned as collaborators but their roles were not clear in this project.

Reviewer 4:
The reviewer said that the project identified a few challenges in designing and optimizing a wireless charging system, and integrating it into a larger DC/DC converter. The project is feasible, but should look at past DOE power electronic projects to try and learn from them. The reviewer noted that the team has NREL assisting with thermal management. The thermal management challenge during wireless charging was highlighted by this reviewer, who also asked if there is any power load required during charging (wireless transfer electronics, DC/DC electronics, battery, etc.). The reviewer said that estimated efficiencies (translates to heat load) should be considered early in the design/evaluation/simulation process.

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

Reviewer 1:
The reviewer said that technical progress is good to this point, and that direction and progress is in line with DOE goals.

Reviewer 2:
The reviewer said that some progress has been achieved. Several topologies have been studied but as indicated by the presenter, the final topology has not been selected. The project proposed secondary side power regulation. The reviewer noted that only a system-level design was performed in FY 2017, and that hardware design and validation will be performed in FY 2018.

Reviewer 3:
The reviewer said that the project did not list the performance indicators it was trying to meet, other than design a smaller wireless charger. An initial simulation verified the wireless circuit design. The reviewer said that the overall goal of the project, to reduce the size of the charging interface, is one that would help DOE get to its goal of more hybridization.

Reviewer 4:
The reviewer remarked that this is a newly started program, and so far, the progress is okay.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that collaborating with NREL is the right path for the thermal work, and that there are many skilled and capable resources at NREL in this area.

Reviewer 2:
The reviewer noted that NREL has good capability for thermal performance development, and it is a good collaboration between the national laboratories.

Reviewer 3:
The reviewer noted that NREL is mentioned as a partner in thermal management, but there is no mention of any specific goals and coordination. The reviewer pointed out that several ORNL staff members are mentioned but their roles are not mentioned.

Reviewer 4:
The reviewer said that the project is utilizing NREL to help with power management, but it lacks coordination with other institutions and vehicle OEMs. The reviewer noted that one audience member pointed out that lessons learned from DOE power electronics projects from last year's AMR do not appear to be incorporated into this project. The reviewer said it would help if the project went back and looked at recent past projects, and tried to collaborate with industry and other organizations in DOE to reduce the project learning curve.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner 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 a good plan moving forward, and the project team obviously understands the elements yet to be engineered.

Reviewer 2:
The reviewer said that the plan for hardware implementation is not clear, and that specifications for hardware performance such as efficiency, power density, etc. are not given. The reviewer said that the size of the ferrite coil is given as the limiting factor in hardware implementation but a risk mitigation strategy is not proposed.

Reviewer 3:
The reviewer said that the proposed future work is logical, but only listed at a high level. At a high level the project has good goals, but goals need to be broken down to trackable milestones and targets. The reviewer said that the project is lacking decision points beyond a simulation study of an 11 kW charger design in September 2017. The reviewer said that the few barriers that were listed were very high-level. The reviewer said that the project did not list specific barriers, or list alternative pathways to mitigate risk.

Reviewer 4:
The reviewer said that because the boost converter is shared by an existing power inverter module, the focus should be on the 11 kW wireless charger side.

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

Reviewer 1:
The reviewer affirmed yes, the project does support the overall objectives. EV charging infrastructure and technology is critical to the adoption of non-internal combustion engine vehicles.

Reviewer 2:
The reviewer said that wireless charging is one of the key components to widespread EV deployment.

Reviewer 3:
The reviewer said that vehicle charging is a key part of pure electric and plug in vehicles. Having a safe, easy method to charge the vehicle, while having a low cost, is critical to adoption. The reviewer said this project helps with the wireless charging and low-cost pieces, which will help DOE meet its objective.

Reviewer 4:
The reviewer said it saves the cost and weight for wireless charger by sharing with a traction inverter boost converter.

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

Reviewer 1:
The reviewer said that the project appears to be running on track, and the resources appear to be sufficient.

Reviewer 2:
The reviewer said this project seems to have sufficient funds based on FY 2017 funding of $650,000.

Reviewer 3:
The reviewer said that seemingly ORNL has staffed the project adequately and is making solid progress. The team seems to be on track and is managing the project accordingly.

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

Presentation Number: edt078
Presentation Title: Power Electronics Thermal Management
Principal Investigator: Gilbert Moreno (National Renewable Energy Laboratory)

Presenter
Gilbert Moreno, National Renewable Energy Laboratory

Reviewer Sample Size
A total of three reviewers evaluated this project

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

Reviewer 1:
The reviewer said that the technical barriers are generic to all power electronic cooling systems. The project is well-designed with several alternative thermal management schemes. There are three collaborative groups and their tasks are well defined.

Reviewer 2:
The reviewer said that NREL is evaluating multiple strategies for cooling power electronics. By studying inverters currently in production, the project team is able to evaluate the pros and cons of each system. The reviewer observed a solid approach.

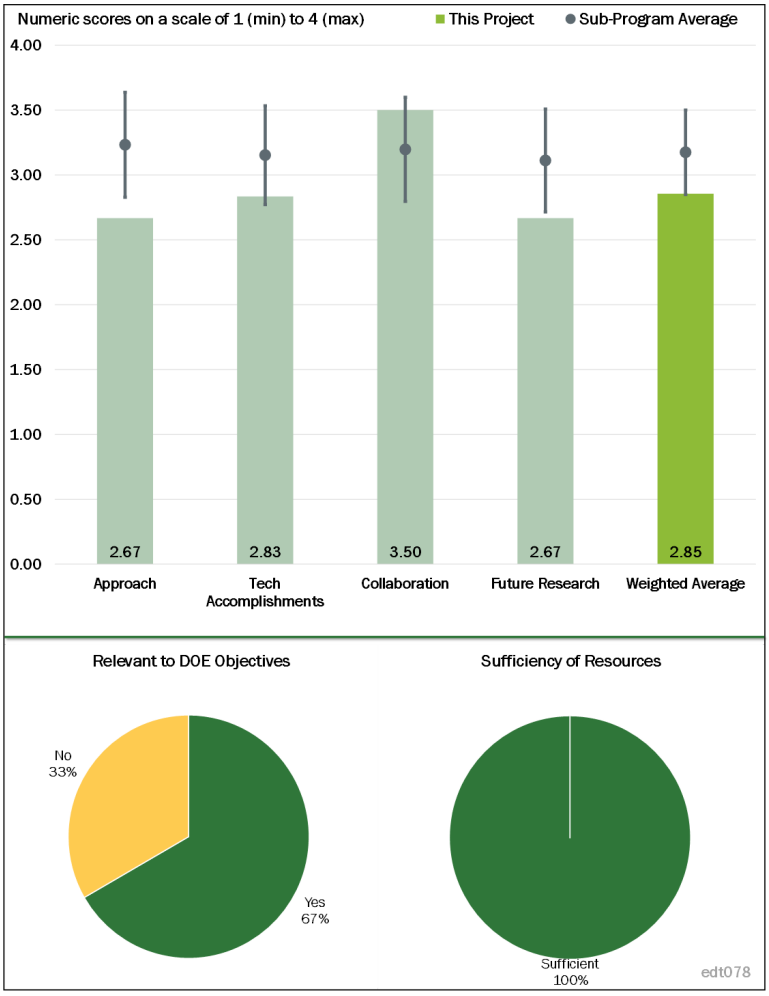

Figure 2-8 - Presentation Number: edt078 Presentation Title: Power Electronics Thermal Management Principal Investigator: Gilbert Moreno (National Renewable Energy Laboratory)

Reviewer 3:
Regarding the approach, the reviewer asked what led to the decision to use the 2012 Nissan LEAF inverter as the benchmark for automotive power electronics thermal management. The reviewer noted that many other automotive inverters as benchmarked by ORNL should have led to a higher level of thermal management strategies as the starting point for advancing thermal design.

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

Reviewer 1:
The reviewer said that this work is directed towards capacitor cooling. Computed capacitor temperatures were given but they were not verified by experimental measurements. The reviewer noted that the project investigated several capacitor cooling strategies for four different inverter configurations. A baseplate-cooled design was shown to reduce heat spreading on the module, which lowers capacitor and gate driver temperatures.

Reviewer 2:
The reviewer said that NREL seems to be moving in the correct direction, but could accelerate their efforts. The reviewer noted that the first stage of this project is primarily benchmarking.

Reviewer 3:
The reviewer commented the project is not specifically advancing the present state-of-the art: capacitor heating by power module, thermal interface material (TIM) degradation, capacitor active thermal management, eliminating the TIM layer, bus bar cooling, etc. are all known industry solutions.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that excellent collaboration has been established with John Deere, Kyocera, and ORNL.

Reviewer 2:
The reviewer said that collaboration is sufficient.

Reviewer 3:
The reviewer noted good collaboration with industry and national laboratory partners. While it may be slightly out of scope, the reviewer would like to see power module providers included in the study.

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

Reviewer 1:
The reviewer said that many alternate cooling strategies were considered based on sound engineering judgement, and that risk mitigation will be implemented.

Reviewer 2:
The reviewer said that proposed future strategies need to be detailed to include power module/device manufacturers in order for this work to have longer term value.

Reviewer 3:
The reviewer pointed out that it is very difficult to develop thermal management concepts that are applicable to a wide range of inverter designs.

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

Reviewer 1:
The reviewer said that thermal management is the key to efficient EV power electronic systems.

Reviewer 2:
The reviewer said this work is an enabling technology for electric drive components required for EVs/plug-in hybrid electric vehicles (PHEVs)/hybrid electric vehicles (HEVs)/and fuel cell EVs.

Reviewer 3:
The reviewer said that relative contributions to petroleum displacement appear to be minimal.

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

Reviewer 1:
The reviewer said that resources seem to be sufficient.

Reviewer 2:
The reviewer commented that resources are sufficient.

Reviewer 3:
The reviewer pointed out that the DOE cost share budget is $493,000 for FY 2017.

Presentation Number: edt079
Presentation Title: Materials for Advanced Packaging
Principal Investigator: Andy Weresczack (Oak Ridge National Laboratory)

Presenter
Andy Weresczack, Oak Ridge National Laboratory

Reviewer Sample Size
A total of four reviewers evaluated this project

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

Reviewer 1:
The reviewer said that the project proposed sintered-silver (Ag) interconnect technology with at least a 15-year lifetime. The project uses commercially available Ag pastes and this work is to develop the sintering technique to produce interconnects. The reviewer said that no integration to other efforts is shown, although many partners are mentioned.

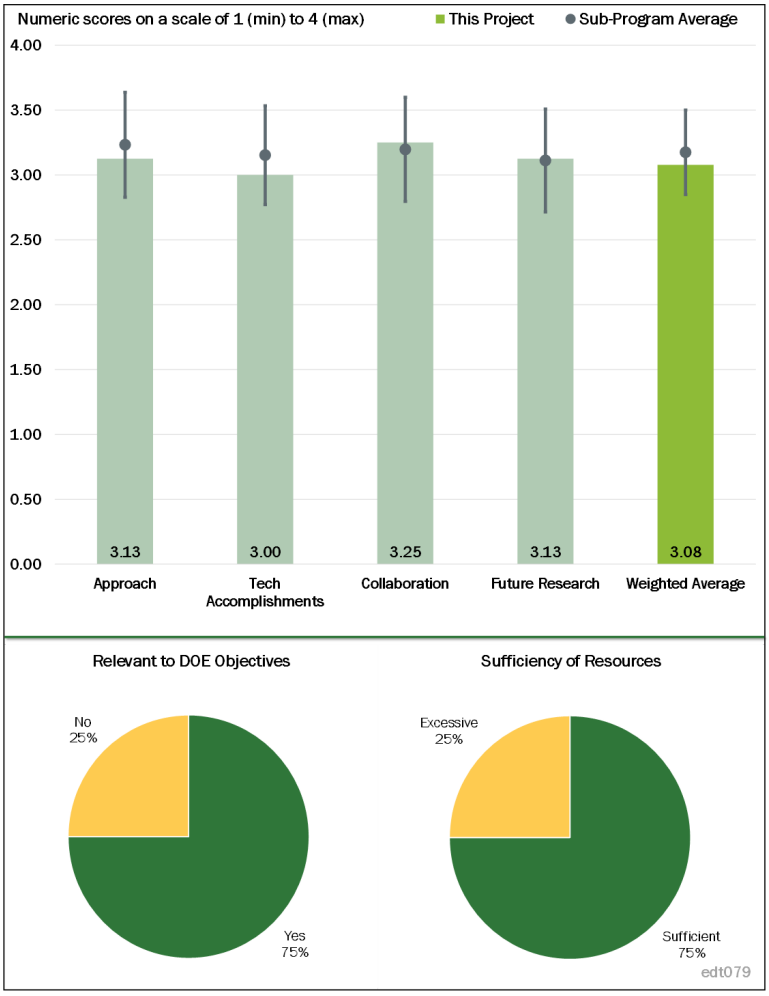

Figure 2-9 – Presentation Number: edt079 Presentation Title: Materials for Advanced Packaging Principal Investigator: Andy Weresczack (Oak Ridge National Laboratory)

Reviewer 2:
The reviewer said that the approach is sound and addresses the technical barriers. The project seems well designed and thoroughly outlined.

Reviewer 3:
The reviewer commented it is a well-designed project focused on a high-temperature bonding technology.

Reviewer 4:
The reviewer said the project advances the processing and mechanical reliability of sintered-Ag for power electronic devices.

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

Reviewer 1:
The reviewer said that the technical accomplishments to date are good and seemingly on track.

Reviewer 2:
The reviewer noted that reduced cost reflow oven processing technology is used for sintered-Ag interconnects to reduce cost. The reviewer said the project developed open contact drying with heat applying from the bottom without pressure of printed sinterable Ag paste. The reviewer detailed that the project developed new test methods for tension/shear using cantilever loading with deep beam theory for correction and apparent fracture toughness measurement using a three-point bending method.

Reviewer 3:
The reviewer said fabricate sufficient numbers of shear test specimens to judge potential of new contact-drying method for printed Ag paste.

Reviewer 4:
The reviewer commented that the project needs to pick up the pace to demonstrate the shear strength of the Ag joints. The shear strength data were not presented.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted excellent collaboration with universities, national laboratories, and industry. According to the reviewer, this is exactly the type of collaboration that will enable this project to succeed.

Reviewer 2:
The reviewer said that collaboration partners are adequate to execute the project.

Reviewer 3:
The reviewer noted that 10 partners are involved in this program.

Reviewer 4:
The reviewer said that there are nine collaborators listed, and some of their roles are not very clear.

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

Reviewer 1:
The reviewer commented that proposed future work is right on track to properly evaluate the feasibility and reliability of this technology.

Reviewer 2:
The reviewer said that future work is well planned for the remainder of FY 2017 and the proposed work for FY 2018 is good. However, there is no alternate development pathway to mitigate risk. The reviewer said that long-term Ag electromigration under large current conduction should be considered.

Reviewer 3:
The reviewer said that the project is identifying the most practical, reliable, and economical Ag (or other metal) plating choice for use with sintered-Ag interconnects.

Reviewer 4:
The reviewer remarked that the future work may be well planned but the reviewer did not see a clear direction from the presentation.

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

Reviewer 1:
The reviewer said yes, this technology will enable high-reliability, low-cost electronics for electric drive applications.

Reviewer 2:
The reviewer said yes, and detailed that the project is focused on high-temperature bonding for WBG devices that will be used in future EVs

Reviewer 3:
The reviewer said to develop advanced sintered-Ag-interconnect technology to enable a 200°C-capable, low-cost, and reliable electronic package with at least a 15 year life.

Reviewer 4:
The reviewer said yes, only if the reduced cost sintered processed Ag interconnects can replace the commonly used Cu interconnects. However, the cost of Ag interconnect may be higher than that of the Cu metal.

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 project resources seem sufficient to achieve the goals of the project. Collaborative agreements with partners will help ORNL move forward with good outside support.

Reviewer 2:
The reviewer pointed out that the FY 2017 funding of $171,000 for this project seems sufficient.

Reviewer 3:
The reviewer found that the resources seem adequate for the project.

Reviewer 4:
The reviewer pointed out that there are 10 partners involved in the project.

Presentation Number: edt080
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 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, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer said that the approach is sound with multiple avenues to examine the technology.

Reviewer 2:
The reviewer said that the sintered-Ag joint may reduce cost, improve reliability and the lifetime of the 200°C power electronic module.

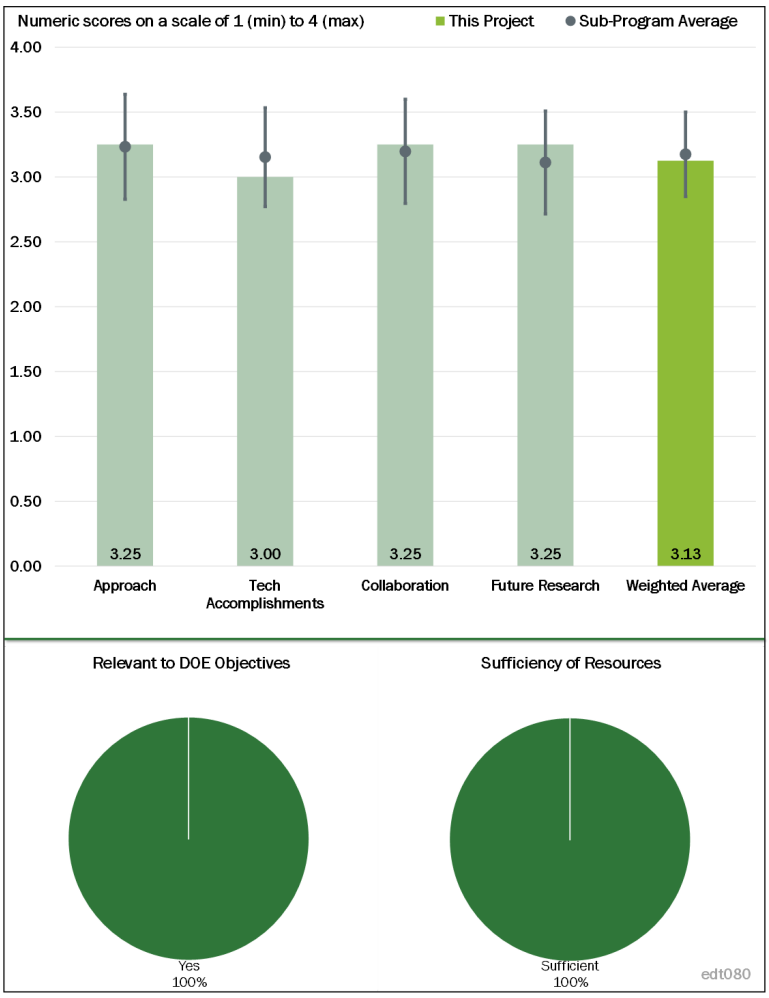

Figure 2-10 - Presentation Number: edt080 Presentation Title: Performance and Reliability of Bonded Interfaces for High-Temperature Packaging Principal Investigator: Paul Paret (National Renewable Energy Laboratory)

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

Reviewer 1:
The reviewer said that accomplishments have been solid, the project seems to be on track and has exhibited good results.

Reviewer 2:
The reviewer commented that mechanical characterization, thermal cycling and finite element method to capture fatigue behavior of sintered-Ag joints were studied. The project performed a shear test using double lap samples in an Instron tester. The project performed tests at Virginia Tech University and NREL, and Cu invar test coupons were used for temperature cycling tests. The project applied an Anand viscoplastic and other material models to sintered-Ag layer to yield J integral/cycle and strain energy density.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed an excellent collaborative arrangement, and technically capable partners.

Reviewer 2:
The reviewer said that concrete collaborations are demonstrated at both NREL and Virginia Tech University.

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

Reviewer 1:
The reviewer said that the planned work is in alignment with the goals of the project and should yield acceptable results.

Reviewer 2:
The reviewer said that additional simulations and experiments, more double lap, complete thermal cycling, and validation of crack propagation models are planned. The reviewer said that the mechanical and reliability aspects of the porosity of the sintered-Ag joints should be investigated.

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

Reviewer 1:
The reviewer said that this study will provide insight and technical results that will enable reliable WBG power modules, which are required for future electric drive inverters.

Reviewer 2:
The reviewer pointed out that sintered-Ag joints can potentially replace the conventional solder joints for power modules operating at 200°C.

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

Reviewer 1:
The reviewer said that it seems that the team is adequately staffed, and has solid partnership arrangements to complete the project.

Reviewer 2:
The reviewer said that the DOE cost-share of funding is $492,000 for FY 2017.

Presentation Number: edt081
Presentation Title: Multilayered Film Capacitors for Advanced Power Electronics and Electric Motors for Electric Traction Drives
Principal Investigator: Deepak Langhe (Polymer Plus)

Presenter
Deepak Langhe, Polymer Plus

Reviewer Sample Size
A total of three reviewers evaluated this project

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

Reviewer 1:
The reviewer said that the project has well-defined technical targets and an interesting process for producing multilayered films. The process should allow for reduced capacitor volume while increasing the operating temperature compared to bi-oriented polypropylene (BOPP) capacitors.

Reviewer 2:
The reviewer said that this approach is outstanding because it is trying to take known materials and capture the best attributes of both.

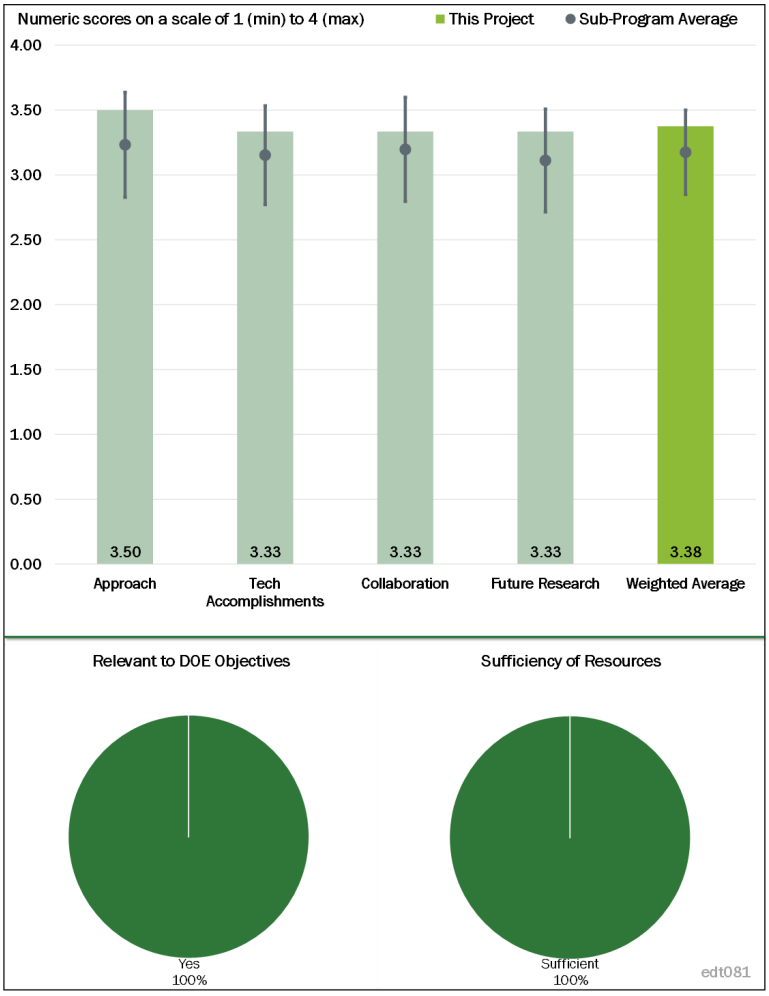

Figure 2-11 – Presentation Number: edt081 Presentation Title: Multilayered Film Capacitors for Advanced Power Electronics and Electric Motors for Electric Traction Drives Principal Investigator: Deepak Langhe (Polymer Plus)

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

Reviewer 1:
The reviewer commented that the project is making real progress with some technical difficulties that the reviewer is confident the team will overcome.

Reviewer 2:
The reviewer detailed that the team was able to produce films down to approximately 4 micrometer (μm), but the film wrinkled significantly during the winding process. The 8μm film produced the best end results and was thus chosen for further study. The team performed thermal modeling to compare the performance of this capacitor to BOPP capacitors. The reviewer noted that several prototypes were built and tested and the team is investigating methods of reducing power loss.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer detailed that the industry partner SBE designs, fabricates, and tests the capacitor prototypes using the films developed by PolymerPlus. ORNL leads the thermal and cost modeling, and Case Western Reserve University investigates the material structure properties and develops new materials.

Reviewer 2:
The reviewer would like to see participation from OEMs.

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

Reviewer 1:
The reviewer said that the team plans to improve the film quality so that thin films can be processed without wrinkles, and that several more prototypes and testing rounds are planned.

Reviewer 2:
The reviewer would like to see OEMs engaged or a Tier 1 supplier involved in testing of parts or contributing to the test plan.

Reviewer 3:
The reviewer acknowledged that some good progress has been shown to date, but the reviewer expressed concern that scaling these achievements up while scaling down the film thickness will prove to be a tremendous challenge, and it appears that these challenges are outside the scope of this particular project. Therefore, it is difficult for this reviewer to see the path to DOE program target goals. The reviewer asked if there are proposed alternate paths to address these.

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

Reviewer 1:
The reviewer said reducing the capacitor size and allowing the inverter to operate at higher temperatures, and that both contribute to the size reduction of the overall inverter system.

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

Reviewer 1:
The reviewer said that the resources appear to be sufficient for this project.

Presentation Number: edt082
Presentation Title: Highly Integrated Wide Bandgap Power Module for Next Generation Plug-In Vehicles
Principal Investigator: Brian Peaslee (General Motors)

Presenter
Brian Peaslee, 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, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer commented that the project appears to be demonstrating and focusing on the key benefits or issues with SiC MOSFET devices, including size reduction, power electronics efficiency, motor efficiency, thermal performance, and efforts to reduce inductance. The DC voltage of 600V is listed, but it seems the potential of SiC would enable higher voltages. The reviewer said that information regarding the tradeoffs of DC voltage and why 600V was selected would be interesting.

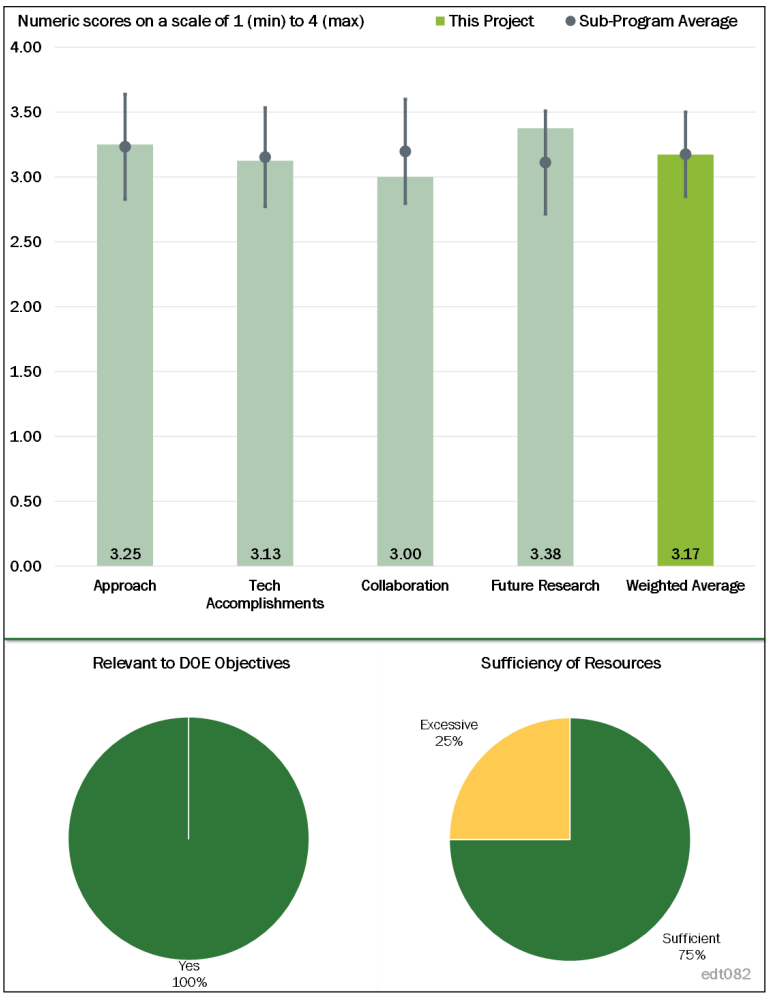

Figure 2-12 – Presentation Number: edt082 Presentation Title: Highly Integrated Wide Bandgap Power Module for Next Generation Plug-In Vehicles Principal Investigator: Brian Peaslee (General Motors)

Reviewer 2:
The reviewer detailed that the project is to enable an inverter to meet or exceed DOE's 2020 target with a power density of 13.4kW/L, a specific power of 14.1kW/kg and $3.3/kW at efficiency of greater than 94% at 10-100% speed at 20% rated torque. The proposed solution is to integrate gate drivers inside WBG power modules to address the barriers of cost, reliability performance, mass and volume. The reviewer said that the goal is to increase the bus voltage to 600VDC. The reviewer said that the presenter should make clear how this increased bus voltage can address the technical barriers because WBG (assuming SiC devices) are already mostly rated at 1,200V even though 900V devices are commercially available. The reviewer asked if there is a large price differential among the 900V and 1,200V devices.

The reviewer noted that GM is the lead with Virginia Tech University, Monolith Semiconductor, and ORNL as the sub-recipients. Cree Wolfspeed is the key supplier and PowerAmerica is the collaborator.

Reviewer 3:
The reviewer said that test results, perhaps in the next phase, can help verify the effectiveness of the SiC MOSFET and the suggested advantages over insulated gate bipolar transistors (IGBT) power modules.

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

Reviewer 1:
The reviewer said that the progress made thus far seems to line up with the intended plan.

Reviewer 2:
The reviewer noted that a two-layer sintering process patent was filed. No SBD was used as extra loss is low and furthermore, the SBD does not have a significant role in reducing switching losses for third-generation SiC MOSFETs. The reviewer said that power module thermal performance has margin without SBD. The reviewer said reduce overall parasitic inductance to below 5 nanohenries, and that signal path inductance is found to be important. Package inductance and thermal performance have been modeled and are below target. Employing a high-voltage motor, such as 600V, compatible with WBG could reduce cycle average losses. The reviewer noted that efficiency is not known, and there have been many investigations for third-generation SiC MOSFETs without SBD by device manufacturers.

Reviewer 3:
The reviewer commented that based on the presented information, the project appears to have made excellent progress in developing preliminary analysis, device selection, and initial design evaluation. It will be interesting to learn more about the design and challenges encountered as the project progresses. The reviewer commented that the loss reductions highlighted appear to be significant but no relative numbers are provided for comparison. This is also true for other graphs in the presentation. The reviewer asked how significant the loss reduction is in terms of energy savings in the vehicle in fuel use or range. It would be interesting to highlight the expected benefits and how this impacts the cost comparison with Si devices. The reviewer asked what the expected system cost benefits for SiC are.

Reviewer 4:
The reviewer noted good progress overall but it appears that the delay in selecting a SiC die caused by issues with Wolfspeed had slowed progress quite a bit. The reviewer hopes that now this is behind the team, it can get on with building and testing to verify what appears to have been some substantial and good modeling/simulation work.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer pointed out that GM is the lead investigator, and Virginia Tech University, ORNL, and Monolith Semiconductor are the sub-recipients, while Wolfspeed is the supplier. PowerAmerica is the collaborator.

Reviewer 2:
The reviewer said that the project appears to involve good collaborations with other partners. The slides specifically highlight work performed by Virginia Tech University. The reviewer said it would be helpful to identify the roles of other partners such as ORNL, and it was not clear how PowerAmerica is collaborating on the project.

Reviewer 3:
The reviewer said the details of the collaboration are not quite clear from the materials on the presentation file.

Reviewer 4:
The reviewer noted good collaboration with Virginia Tech University and device suppliers or potential device suppliers. The reviewer said it was not clear what the collaboration and contribution is of ORNL is and the reviewer is unsure that they can contribute.

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

Reviewer 1:
The reviewer said that the highlighted future research appears to be aligned with the project goals. The reviewer noted that the challenge of higher temperature encapsulates and capacitors were listed, but there does not appear to be future work listed in these areas.

Reviewer 2:
The reviewer said that the current steps as presented for the future plan are sound and reasonable. However, a backup plan in case of failure of the suggested approach is not outlined. Also, it was unclear to this reviewer what the go/no-go criteria are as the future plan is based on a go/no-go review.

Reviewer 3:
The reviewer observed logical, orderly next steps. The reviewer agreed that the high-bandwidth current sense (using Rogowski coils), desaturation protection, and common-mode transient immunity that the principal investigator pointed out as "Challenges & Potential Barriers" are indeed potential problems. The reviewer would like to see the work associated with investigating/addressing these more prominently featured in the project and task lists

Reviewer 4:
The reviewer noted that high-bandwidth, low-cost current sensing, high-temperature encapsulate and capacitors are planned. Gate driver improvement will be implemented with three times more short circuit current protection than that of typical Si IGBT. The team plans a desaturation protection scheme and will investigate a high common-mode transient immunity.

The team will perform sintering trials and will build a half bridge configuration. The reviewer asked for the gate driver, what the criteria for this go/no-go gate review are. The reviewer cited a lack of detailed design, coupon construction and confirmation tests.

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

Reviewer 1:
The reviewer remarked yes, it supports the overall DOE objectives from the work done to date and the future plan when compared against the primary objectives.

Reviewer 2:
The reviewer said that highly integrated WBG power modules are essential for next-generation EVs to meet DOE objectives of petroleum displacement.

Reviewer 3:
The reviewer said that the development of electric drive components such as this SiC power module directly contribute to energy savings within vehicle applications.

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

Reviewer 1:
The reviewer remarked that even though the resources are not detailed in the presentation file, overall, from the Overview and Relevance slides, it seems that they are sufficient.

Reviewer 2:
The reviewer said that the project appears to have a significant budget to accomplish the project goals.

Reviewer 3:
The reviewer said that a total budget of $5.67 million seems excessive for this power module project.

Presentation Number: edt083
Presentation Title: 650V SiC Integrated Power Module for Automotive Inverters
Principal Investigator: Monty Hayes (Delphi Automotive Systems, LLC)

Presenter
Monty Hayes, Delphi Automotive Systems, LLC

Reviewer Sample Size
A total of four reviewers evaluated this project

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

Reviewer 1:
The reviewer said that the approach is sound, and it is in alignment with the goals of the project.

Reviewer 2:
The reviewer observed a target for bus voltages lower than 650V, and noted a 650V single switch device with double sided cooling and a half-bridge inverter. The reviewer asked if there is significant price differential among the 1,200V, 900V and 650V SiC devices.

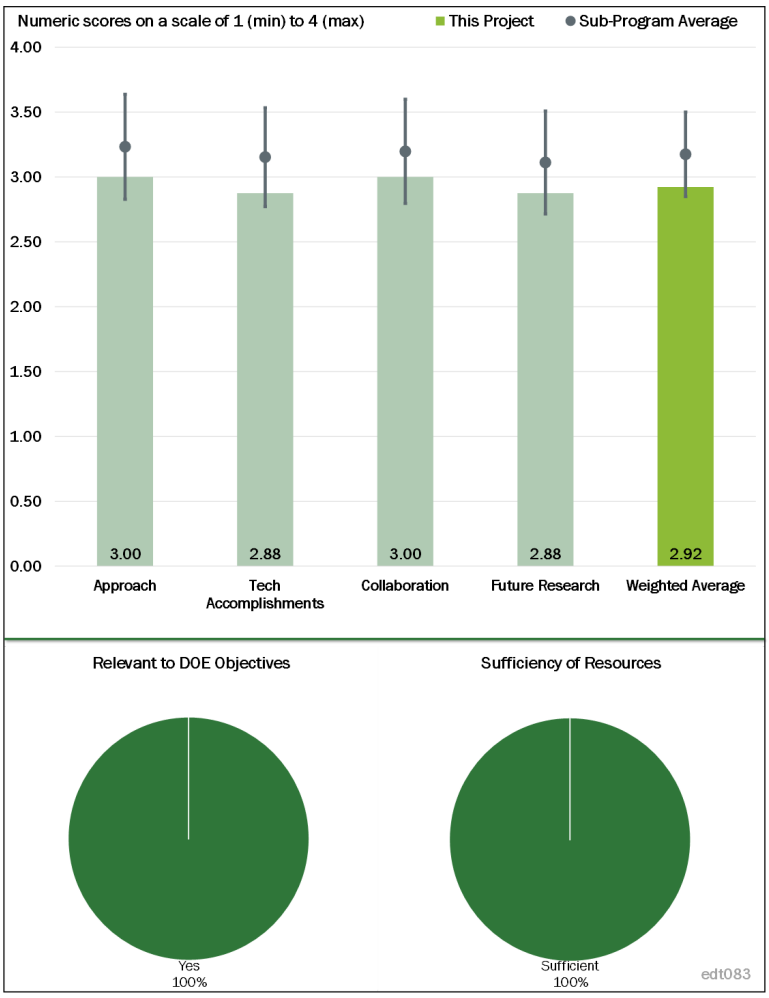

Figure 2-13 - Presentation Number: edt083 Presentation Title: 650V SiC Integrated Power Module for Automotive Inverters Principal Investigator: Monty Hayes (Delphi Automotive Systems, LLC)

Reviewer 3:
The reviewer said the major concern is the completion rate after about 1.5 years since the project started. Some of the objectives, such as the current rating of a single switch, have not been met in the design and fabrication. The reviewer noted that some of the remaining barriers are significant, especially with the amount of project time left. Among those are the cost-effectiveness and the final prototype fabrication, test and modification (if need be).

Reviewer 4:
The reviewer said that the project does not seem to have enough time for testing before starting a second iteration.

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

Reviewer 1:
The reviewer said that the early results indicate that the project is on the right track.

Reviewer 2:
The reviewer noted a paralleling of five devices, 500 ampere root mean square (A_{rms}) single switch capability with thermistor on package, and Wolfspeed 650V G3 MOSFETs 75 amp at 25°C. The reviewer noted optimized gate resistance inside the package, and ability to control the di/dt and reduced oscillations. The reviewer said that static and dynamic characterization were performed, thermal characterization of heat sink assembly, and that the team investigated SiC inverter losses using a three-phase inductive load.

Reviewer 3:
The reviewer said that the progress made to date is significantly behind the projected percentage.

Reviewer 4:
The reviewer would like to have Delphi provide understanding of drivers in part yield.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that the collaboration is clearly indicated.

Reviewer 2:
The reviewer said that the project has good collaboration and the appropriate partnerships to be successful.

Reviewer 3:
The reviewer noted that Wolfspeed, ORNL, and Volvo are the partners and their roles are listed. It is not clear what the roles of Volvo are.

Reviewer 4:
The reviewer observed no discussion about the extent to which each party is collaborating.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner 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 proposed future work and project plan is in alignment with the objectives and goals of the project. Successful completion of this work should result in the team meeting the project goals.

Reviewer 2:
The reviewer said that future tasks are planned but more details are needed.

Reviewer 3:
The reviewer said that while the project needs some expedition, such plans or alternative development pathways are not outlined.

Reviewer 4:
The reviewer remarked that packaging the SiC device is an important step, but is just one of many elements needed to see incorporation of the technology. The reviewer is sure Delphi understands this comment and the need for more extensive work to move this technology into a vehicle.

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

Reviewer 1:
The reviewer said that cost-effective WBG power modules are essential for EV deployment to meet the overall DOE objectives of petroleum displacement.

Reviewer 2:
The reviewer said yes, SiC inverters are the next step toward smaller, lighter, higher voltage traction inverters.

Reviewer 3:
The reviewer commented that as per the objectives of the project, the work done and the future work to be completed are relevant to DOE objectives.

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

Reviewer 1:
The reviewer commented that a total budget of $2.16 million seems to be sufficient for the project.

Reviewer 2:
The reviewer said that the team is adequately staffed, and should be able to successfully complete the project.

Reviewer 3:
The reviewer said that even though the resources are not clearly mentioned in the presentation, it seems that they are sufficient.

Presentation Number: edt087
Presentation Title: Electrical Performance, Reliability Analysis, and Characterization
Principal Investigator: Tim Burress (Oak Ridge National Laboratory)

Presenter
Tim Burress, 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, feasible, and integrated with other efforts.

Reviewer 1:
The reviewer said that the work is well organized and the approach is sound.

Reviewer 2:
The reviewer said that continuing to benchmark commercially available electric drivetrains is extremely valuable to the broader technical community, and that it also helps establish trends.

Reviewer 3:
The reviewer said this is a well-designed project that is gathering valuable data on the design and performance of production HEV systems and components.

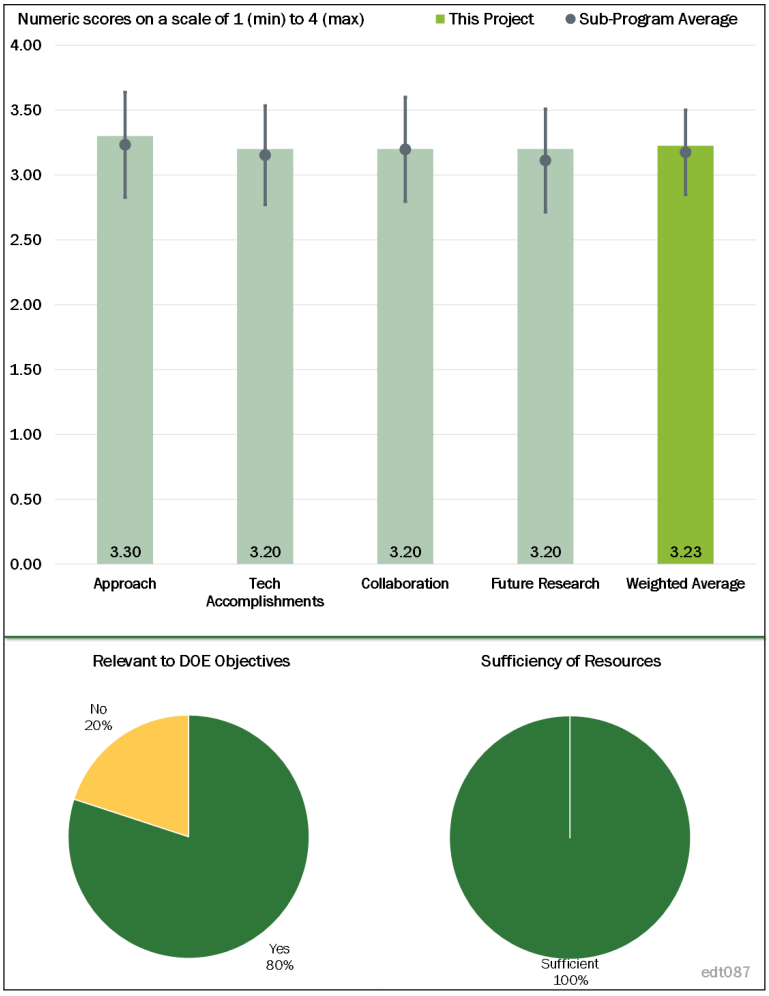

Figure 2-14 – Presentation Number: edt087 Presentation Title: Electrical Performance, Reliability Analysis, and Characterization Principal Investigator: Tim Burress (Oak Ridge National Laboratory)

Reviewer 4:
The reviewer said the core function of this project is to confirm power electronics and electric motor technology status and identify barriers and gaps to prioritize and identify R&D opportunities. This project helps with program planning and the establishment and verification of all of DOE's 2020 targets.

Reviewer 5:
The reviewer said the project shows a comparison of several HEV architectures. The project does not provide any information on how this information will be used to identify gaps/challenges.

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

Reviewer 1:
The reviewer said this project is making excellent progress towards meeting all of its goals. It is well aligned with DOE goals pertaining to the development of advanced electric motor technology.

Reviewer 2:
The reviewer said great progress was made. Year after year more EDTs are benchmarked and compared to previous generations, which is extremely valuable. The reviewer said that great progress was made in terms of benchmarking the Prius 2017 EDT.

Reviewer 3:
The reviewer said obtain and publish detailed information on state-of-the-art technologies and their progression, and complete the 2017 Prius power control unit tear-down.

Reviewer 4:
The reviewer said that this project, in essence, is a benchmarking project. While there were technical challenges to overcome, they were directly related to controlling the motor/inverter. The demonstration of the system has some value to DOE, but the reviewer would state that it is of minimal value towards achieving DOE's goals.

Reviewer 5:
The reviewer said that the progress is okay but the goals were not clear.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that this project is effectively collaborating with Argonne National Laboratory (ANL) and NREL and receiving relevant system and component data from them.

Reviewer 2:
The reviewer said there is excellent collaboration between ORNL and their contributors, NREL and ANL.

Reviewer 3:
The reviewer noted that the project has three national laboratories involved.

Reviewer 4:
The reviewer commented that it seems the work is largely done within ORNL and there is some level of collaboration with other national laboratories.

Reviewer 5:
The reviewer commented that only ORNL was part of the project.

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

Reviewer 1:
The reviewer said that finishing the benchmarking of the 2017 Prius as well as continuing to benchmark other new EDTs as they become available is an excellent direction.

Reviewer 2:
The reviewer said this project has a well-defined plan for future research. The reviewer said that if possible, the project should consider including component-level characterization of the main active components (magnets, conductors, IGBT's) to verify their performance.

Reviewer 3:
The reviewer said the future work was presented but the direction of the work was not clear.

Reviewer 4:
The reviewer said that with limited funding for EDTs, this work should be re-evaluated. The overall benefit to VTO and the OEMs is minimal. The reviewer would term it "nice to have" but not mission critical.

Reviewer 5:
The reviewer said select commercially available EV/HEV systems relevant to DOE's VTO mission to help to determine DOE's 2020 goal.

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

Reviewer 1:
The reviewer replied yes, to the extent that it gives DOE more information on the systems currently being deployed versus the DOE targets in 2020 and 2025.

Reviewer 2:
The reviewer said that benchmarking commercially available EDTs and establishing trends is extremely valuable in terms of confirming and if needed modifying the technology roadmap to meet DOE targets.

Reviewer 3:
The reviewer said yes, this project is providing valuable performance data of production electric motor systems and components. These data will serve as a baseline that future advanced motor designs can be compared against. The reviewer remarked that the comparison will provide a means of assessing the competitiveness of those design, enabling manufacturers to make informed choices on market introduction of new products.

Reviewer 4:
The reviewer said that it was not quite clear on this aspect as the future direction was not presented.

Reviewer 5:
The reviewer said that the core function of this project is to confirm power electronics and electric motor technology status and identify barriers and gaps to prioritize and identify R&D opportunities.

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 the resources are adequate.

Reviewer 2:
The reviewer said that based on the scope, the level of funding seems sufficient.

Reviewer 3:
The reviewer said that the resources of the project appear to be sufficient to meet the stated milestones.

Reviewer 4:
The reviewer believed the resource are adequate.

Reviewer 5:
The reviewer commented that this team has a good record of benchmarking the series of HEV/PHEV power inverters in the past. The reviewer said that so far the team has made good progress on the 2017 Prius tear-down.

Acronyms and Abbreviations

µm	Micrometer (micron)
^{0}C	Celsius (Centigrade)
Ag	Silver
AlNiCo	Aluminum-nickel-cobalt
AMR	Annual Merit Review
ANL	Argonne National Laboratory
A_{rms}	Ampere root mean square
BOPP	Bi-oriented polypropylene
CNT	Carbon nanotubes
Cu	Copper
DC	Direct current
DOE	U.S. Department of Energy
DREaM	Development of Radically Enhanced alnico Magnets
ED	Electric drive
EDT	Electric Drive Technologies
EMC	Electromagnetic compatibility
EV	Electric vehicle
FeSi	Ferrosilicon
FY	Fiscal year
GaN	Gallium nitride
GM	General Motors
HEV	Hybrid electric vehicle
IGBT	Insulated-gate bipolar transistors
kW	Kilowatt
MOSFET	Metal–oxide–semiconductor field-effect transistor
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory

OEM	Original equipment manufacturer
ORNL	Oak Ridge National Laboratory
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
R&D	Research and development
Rds(on)	Resistance from drain to source
RE	Rare earth
SAE	Society of Automotive Engineers
SBD	Schottky barrier diodes
Si	Silicon
SiC	Silicon carbide
SynchRel	Synchronous reluctance
TIM	Thermal interface material
U.S.	United States
U.S. DRIVE	United States Driving Research and Innovation for Vehicle efficiency and Energy sustainability
V	Volt
VTO	Vehicle Technologies Office
WBG	Wide bandgap