3. Electric Drive Technologies

Electric drive technologies (EDT), including the electric motor, inverter, boost converter, and on-board charger, are essential components of hybrid and plug-in electric vehicle (PEV) propulsion systems. The Vehicle Technologies Office (VTO) supports research and development (R&D) to reduce the cost and improve the performance of innovative electric drive devices, components, and systems.

Reducing the cost of electric drive vehicles (EDVs) is essential for increasing consumer adoption and meeting the EV Everywhere Grand Challenge goal. EV Everywhere is a Clean Energy Grand Challenge for PEVs that are as affordable and convenient for the American family as gasoline-powered vehicles by 2022.

VTO funds research to advance EDT in two key areas:

- Power electronics (PE); and
- Electric motors.

VTO funds research on EDT to:

- Reduce cost, weight, and volume;
- Improve performance, efficienc , and reliability;
- Develop innovative modular and scalable designs; and
- Improve manufacturability and accelerate commercialization.

Within these areas, VTO focuses on:

- Wide bandgap (WBG) devices for power electronics;
- Advanced motor designs to reduce or eliminate rare earth (RE) materials;
- Novel packaging for power electronics and electric motors;
- Improvements in thermal management and reliability; and
- Integration of power electronics functions.

VTO works extensively with a number of different organizations. The EDT subprogram supports a number of unique user facilities at the national laboratories. Within the U.S. Department of Energy (DOE), the office collaborates with the Office of Science, Advanced Research Projects Agency-Energy (ARPA-e), and the Clean Energy Manufacturing Initiative Across the federal government, the EDT subprogram works with:

- The National Network for Manufacturing Innovation;
- The Interagency Advanced Power Group; and
- The U.S. Army Tank, Automotive Research and Development and Engineering Center (TARDEC) in the U.S. Department of Defense.

Much of the subprogram's research is conducted in sync with industry partners through:

- The United States Driving Research and Innovation for Vehicle efficiency and Energy sustainability (U.S. DRIVE) Partnership focusing on light-duty vehicles; and
- The 21st Century Truck Partnership, focusing on heavy-duty vehicles.

As described in the EV Everywhere Blueprint, the major goals of the subprogram are to reduce the cost of electric drive systems by half and decrease their volume by one-third by 2022.

Subprogram Feedback

The U.S. Department of Energy (DOE) received feedback on the overall technical subprogram areas presented during the 2016 Annual Merit Review (AMR). Each subprogram technical session was introduced with a presentation that provided an overview of subprogram goals and recent progress, followed by a series of detailed topic area project presentations.

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

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

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

Question 3: Were important issues and challenges identified?

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

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

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

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

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

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

Question 10: Has the program area engaged appropriate partners?

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

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

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

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

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

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

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

Overview of the VTO Electric Drive Technologies Program: Susan Rogers (U.S. Department of Energy) - edt000

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

Reviewer 1:
The reviewer agreed that all of the activities of the program were adequately covered. The reviewer also commented that the strategic goals of the program were very clearly presented and that industry engagement was mentioned. One recommendation made by the reviewer is to more explicitly describe how the value chain of advanced EDT components is being developed.

Reviewer 2:
The reviewer stated that it was a good overview that covered the area adequately.

Reviewer 3:
The reviewer replied yes to this question.

Reviewer 4:
The reviewer observed that the vehicle program covers a comprehensive set of areas including the traction machines, traction inverters, and battery charger, and that the traction machine area covers new materials, new machine topologies, and packaging. The reviewer also noted that the power converter area covers the application of next generation WBG semiconductors, thermal management, and additive manufacturing of power converter heat sinks.

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

Reviewer 1:
The reviewer agreed that the program has a balanced near-, mid-, and long-term R&D plan to achieve the goals in cost reduction, power density, and energy saving. This reviewer also noted greater adoption of hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and battery electric vehicle (BEV) technology.

Reviewer 2:
The reviewer replied yes to this question.

Reviewer 3:
The reviewer commented that the research portfolio is centered at a point between mid- and long-term research. The reviewer also observed that near-term research is represented, particularly in the advanced manufacturing of capacitors and power electronics, and that the mid-term focus on advanced packaging for WBG components is appropriate. The reviewer recommended some focus on long-term WBG components, for example, the impact of the next generation of semiconductors beyond silicon carbide (SiC) and gallium nitride (GaN) on EDT. This would be a good opportunity to integrate the results of advanced WBG work funded by ARPA-E.

Reviewer 4:
The reviewer remarked that the near- and-mid-term research goals up to 2022 were well identified and that the balanced approach to research topic areas and funding is an effective approach and creates a good balance of technologies. However, the reviewer stated that long term (i.e., far out, hard to achieve) research was not identified, adding that while general statements were made for looking forward statements, there was not a path mapped or specific research identified to get ther

Question 3: Were important issues and challenges identified?

Reviewer 1:
The reviewer stated that the program identified the following major challenges: cost and size reduction of traction

motor (using non-rare earth [NREL]) materials, new materials for laminations, and thermal management), packaging, and thermal management of power converters using WBG devices and their reliability.

Reviewer 2:
The reviewer agreed that important issues and challenges were identified, adding that cost was the la gest concern area identified

Reviewer 3:
The reviewer replied yes to this question.

Reviewer 4:
The reviewer remarked that the focus on reducing system cost was clear and appropriate with improved manufacturability a complementary goal. However, the reviewer commented that less emphasis was explicitly placed on system and component reliability although it was mentioned. The reviewer's recommendation would be to identify system end-of-life management (recycling and/or remanufacturing) as an important challenge.

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

Reviewer 1:
The reviewer commented that the roadmap for achieving the 2022 targets was clear and very well presented, and that it provided an appropriately-graded strategy that segmented the development needs for component technologies into an appropriate timeline. The reviewer offered that the rates of improvement in the system performance metrics that are needed to meet the 2022 targets are aggressive.

Reviewer 2:
The reviewer replied yes to this question.

Reviewer 3:
The reviewer observed that the program plans to engage national laboratories, universities, original equipment manufacturers (OEMs), and suppliers to tackle the above-mentioned challenges through benchmarking and new technology development and verification

Reviewer 4:
The reviewer stated that the plan to address the issues and challenges was to engage the right team focusing including research and manufacturing, in conjunction with educating engineers at OEMs who are making design choices. The team includes national laboratories, universities, and manufacturers.

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

Reviewer 1:
The reviewer stated that progress was clearly stated against the previous year including the cost reduction and power density improvement.

Reviewer 2:
The reviewer replied yes to this question.

Reviewer 3:
The reviewer commented that progress was benchmarked against the overall system development activities that have been undertaken since 1995 and added that a specific benchmark of progress made against the 2014 achievements was not observed.

Reviewer 4:
The reviewer indicated that benchmarking at the low level (individual year by year) was not presented, although a history of past achievements was presented at a macro level to show that progress is being made longer term.

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 affirmed that there is good progress being made to solve broad problems and barriers with the goal to have affordable, higher efficiency vehicles for the mass market through electrificatio

Reviewer 2:
The reviewer stated that this program is centered on meeting part of the technological challenges identified in the EV Everywhere Grand Challenge and agreed that the scope of EDT is appropriately focused on electric machine and power electronics systems and component technologies.

Reviewer 3:
The reviewer replied yes to this question.

Reviewer 4:
The reviewer remarked that the projects in this technology area contribute to the VTO from the aspect of electric drive train technology including the traction electric machines, traction power converters, and battery chargers.

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

Reviewer 1:
The reviewer agreed that the project's focus is appropriate for VTO goals and objectives, adding that the management team is experienced and has been effective in managing the research portfolio over the past several years.

Reviewer 2:
The reviewer indicated that the program area is effective in addressing VTO's needs in vehicle electric drivetrain technology.

Reviewer 3:
The reviewer replied yes to this question.

Reviewer 4:
The reviewer stated that the program appears to be well managed and effectively advancing the agenda.

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 identified involvement with OEMs as one of the key strengths, adding that the technology is being adopted by industry and really stands out going into production (i.e., 2016 Chevy Volt). The reviewer stated that three-dimensional (3D) printing of cold plates also stands out, as it is a low risk, high potential gain item. Thermal management is one of the challenges identified and historically has been a challenge for power electronics. The reviewer further specified that new approaches like 3D printing to optimize the heat flow are needed and stand ou

Reviewer 2:
The reviewer described as a key strength the program's effective integration of research projects at national laboratories with those demonstration activities done at companies. This close interaction would help speed up technology commercialization.

Reviewer 3:
The reviewer emphasized two key strengths in this program area as the demonstration of advanced power electronic systems that incorporate the latest in advanced manufacturing as well as the latest in WBG devices. The reviewer also identified the development and demonstration of advanced motor designs that use less RE elements as another notable success. The reviewer suggested revisiting the focus on RE reduction as a program goal, pointing out that the rare-earth supply crisis has abated, due in no small part to programs such as this one that have produced system- and component-level substitutes. The reviewer stated that it might be appropriate to expand the focus to include more critical elements beyond REs that could possibly be used in EDT systems. The benefit might be to anticipate and avoid future critical material supply shocks.

Reviewer 4:
The reviewer listed the following two key strengths: existing projects cover many important challenges (e.g., cost and size reduction of motors and power converters); and good collaboration is going on between collaborators). The key weakness observed by the reviewer is that little effort is given to the control of machines and power converters.

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

Reviewer 1:
The reviewer praised these projects as having had a proven track record of investigating and supporting novel approaches to a level where reasonable extrapolations of their system level performance can be made. The reviewer described the projects as having shown a disciplined approach towards redirecting program focus to the most promising areas and demonstrating them at the benchtop or test-stand level.

Reviewer 2:
The reviewer offered that the projects represent innovative approaches to the barriers, such as 3D printing components to optimize weight and thermal management.

Reviewer 3:
The reviewer agreed that most of the projects are innovative.

Question 10: Has the program area engaged appropriate partners?

Reviewer 1:
The reviewer stated the program area has a good mix of national laboratories, academia, and industry.

Reviewer 2:
The reviewer characterized the program area as having engaged appropriate partners including industry, national laboratories, and universities.

Reviewer 3:
The reviewer replied yes to this question.

Reviewer 4:
The reviewer agreed that the program area has identified and engaged the appropriate partners among the national laboratories, academia, OEMs, and Tier 1, 2, and 3 suppliers. The reviewer recommended an increased focus on promoting the formation of supply chains at the component to sub-system level and remarked that the focus on WBG packaging is a good example that could be emulated in other parts of the EDT portfolio.

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

Reviewer 1:
The reviewer affirmed that the program area is collaborating e fectively with its partners, describing the technologies being developed as proven to be effective (both from a technical and cost standpoint) and transitioned to production (e.g., the Chevy Volt).

Reviewer 2:
The reviewer agreed that the program area is effectively collaborating with all of the partner organizations, adding that the list of research highlights was encouraging and shows the progress the program area is making across several fronts.

Reviewer 3:
The reviewer replied yes to this question.

Reviewer 4:
The reviewer stated that collaborating partners have adequate communication going on with each other.

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

Reviewer 1:
The reviewer stated that the portfolio seems to broadly cover the technology sufficientl .

Reviewer 2:
The reviewer replied yes to this question.

Reviewer 3:
The reviewer remarked that, as noted, there may need to be more focus on developing the supply chain at the component to sub-system level.

Reviewer 4:
The reviewer cautioned that the electromagnetic interference (EMI) and electromagnetic compatibility (EMC) issues do not seem to be given enough attention in this program.

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

Reviewer 1:
The reviewer replied no to this question.

Reviewer 2:
The reviewer cautioned that system end-of-life considerations such as recycling and/or remanufacturing of EDT components may warrant more investigation. The reviewer also indicated that the impact of the evolving electric vehicle (EV) market may require more investigation in the future. In particular, the possibility of self-driving vehicles and the future growth of car-sharing services may change the balance of system performance priorities.

Reviewer 3:
The reviewer remarked that the high temperature range and power density metrics are a little weak. The reviewer said that the individual DOE projects and Society of Automotive Engineers (SAE) design practices suggest engine compartment components should be designed for 145 Celsius (°C) to 150°C ambient temperatures. The reviewer recommended helping to identify the operating conditions for the system rather than just the junction temperatures of discrete components. The reviewer noted that junction temperatures are an important enabling technology to get to the end goals (especially integrated power electronics on motors), but that the real design requirements are having the larger operating environment defined (coolant temperatures and ambient). The reviewer stated that it was not readily obvious in the presentation, but in conjunction with other presentations, the power density metrics are unclear. Other presentations refer to these power density metrics as being relatively short duration peak

requirements. The reviewer explained that power density goals should be stated for continuous operation (hours, not a couple of seconds), or at a minimum for both continuous and peak, adding that these would be really good goals if they are for continuous operation.

Reviewer 4:
The reviewer did not see anything related to the controls of machines and power converters.

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

Reviewer 1:
The reviewer judged the program as currently reasonably funded to achieve the proposed work and goals.

Reviewer 2:
The reviewer replied no to this question.

Reviewer 3:
The reviewer stated that the program should also consider adding low temperatures (-40°C to -50°C) requirements in conjunction with high temperatures because some of the design choices chosen to address high temperatures affect low temperature operation. The reviewer pointed out that SAE temperature ranges have a relatively large range to address the Upper Midwest snowbelt states and Alaska.

Reviewer 4:
The reviewer suggested that the program area may wish to evaluate the risk posed by other critical materials in the supply chain for EDT systems and component technology beyond RE ones. The reviewer stated that coordination with the Critical Materials Institute may identify future supply chain risks that may be avoided if prudent investments are made in substitute technologies.

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

Reviewer 1:
The reviewer observed that there may be older technologies that could be used for conventional low-cost electronics that are being overlooked because they were hard to control previously. The reviewer noted new ways to cascade, control, and cool conventional electronics and to reach the cost goals quicker than with WBG. The reviewer said that micro machines integrated in the heat sink used to create closed loop air conditioning (hot side going to an engine temperature cooling loop) may be able to cool conventional electronics more effectively than thermal electric and other methods.

Reviewer 2:
The reviewer stated that coordination with the Vehicles Systems (VS) subprogram can uncover challenges that the evolving EV market may place on EDT systems and components. In particular, the development of self-driving vehicles and car-sharing services may place unforeseen challenges on EDT systems and components.

Reviewer 3:
The reviewer said no.

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

Reviewer 1:
The reviewer stated that this comment is for the effectiveness of the presentation rather than the program area. The

reviewer urged that for the presentation, review the questions that reviewers will be reviewing, make sure they are all covered, and make it blatantly obvious.

Reviewer 2:
The reviewer had no other suggestions.

Reviewer 3:
The reviewer replied no to this question.

Project Feedback

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

Table 3-1 – Project Feedback

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Benchmarking EV and HEV Technologies	Burress, Tim (ORNL)	3-13	3.64	3.79	3.57	3.50	3.69
Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors	Anderson, Iver (Ames)	3-17	3.58	3.42	3.50	3.42	3.47
North American Supply Chain for Traction Motors and PE	Whaling, Christopher (Synthesis Partners)	3-21	3.00	2.67	3.17	2.50	2.79
Advanced Packaging Technologies and Designs†	Liang, Zhenxian (ORNL)	3-23	3.13	3.25	3.00	3.13	3.17
Electric Drive Inverter Research and Development	Chinthavali, Madhu (ORNL)	3-26	3.33	3.08	3.25	3.08	3.17
Innovative Technologies for Converters and Chargers†	Su, Gui-Jia (ORNL)	3-29	3.36	3.36	3.21	3.21	3.32

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Advanced Low-Cost SiC and GaN Wide Bandgap Inverters for Under-the-Hood Electric Vehicle Traction Drives	Olejniczak, Kraig (APEI Inc.)	3-32	3.83	3.83	3.67	3.50	3.77
High Temperature DC-Bus Capacitor Cost Reduction and Performance Improvements	Yializis, Angelo (Sigma Technologies International)	3-35	3.83	3.83	3.33	3.33	3.71
High-Performance DC Bus Film Capacitor	Tan, Dan (General Electric)	3-38	3.33	3.33	3.50	3.17	3.33
Advanced Electric Motor Research	Burress, Tim (ORNL)	3-41	3.25	3.25	3.38	3.00	3.23
Performance and Reliability of Bonded Interfaces for High-Temperature Packaging	DeVoto, Doug (NREL)	3-45	3.30	3.20	3.50	3.00	3.24
Electric Motor Thermal Management Research and Development	Bennion, Kevin (NREL)	3-48	3.50	3.67	3.50	3.50	3.58
High-Efficiency High-Density GaN-Based 6.6 kW Bidirectional On-Board Charger for PEVs	Zhu, Charles (Delta Products Corporation)	3-51	3.25	3.50	3.25	3.25	3.38
Gate Driver Optimization for WBG Applications	Ericson, Nance (ORNL)	3-55	3.20	3.50	3.40	3.30	3.39

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Power Electronics Thermal Managment Research and Development	Moreno, Gilbert (NREL)	3-58	3.33	3.00	3.00	3.00	3.08
Thermal Performance Benchmarking†	Feng, Xuhui (NREL)	3-60	3.38	3.25	3.13	3.13	3.25
Electric Motor Performance Improvement Techniques†	Tang, Lixin (ORNL)	3-63	3.50	3.25	3.25	3.25	3.31
88 Kilowatt Automotive Inverter with New 900 Volt Silicon Carbide MOSFET Technology	Casady, Jeffrey (Cree)	3-67	3.67	3.83	3.67	3.33	3.71
Overall Average			3.41	3.39	3.35	3.20	3.37

† denotes poster presentation.

Benchmarking EV and HEV Technologies: Tim Burress (Oak Ridge National Laboratory) - edt006

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 recognized that this project provides valuable information about state-of-the-art EDT that can be used to improve EV and HEV systems in the United States. This person commented that the approach has proven effective on several other systems.

Reviewer 2:
This reviewer noted it was good that both the motor dyno tests and chassis dyno tests were used to benchmarking the new vehicle products.

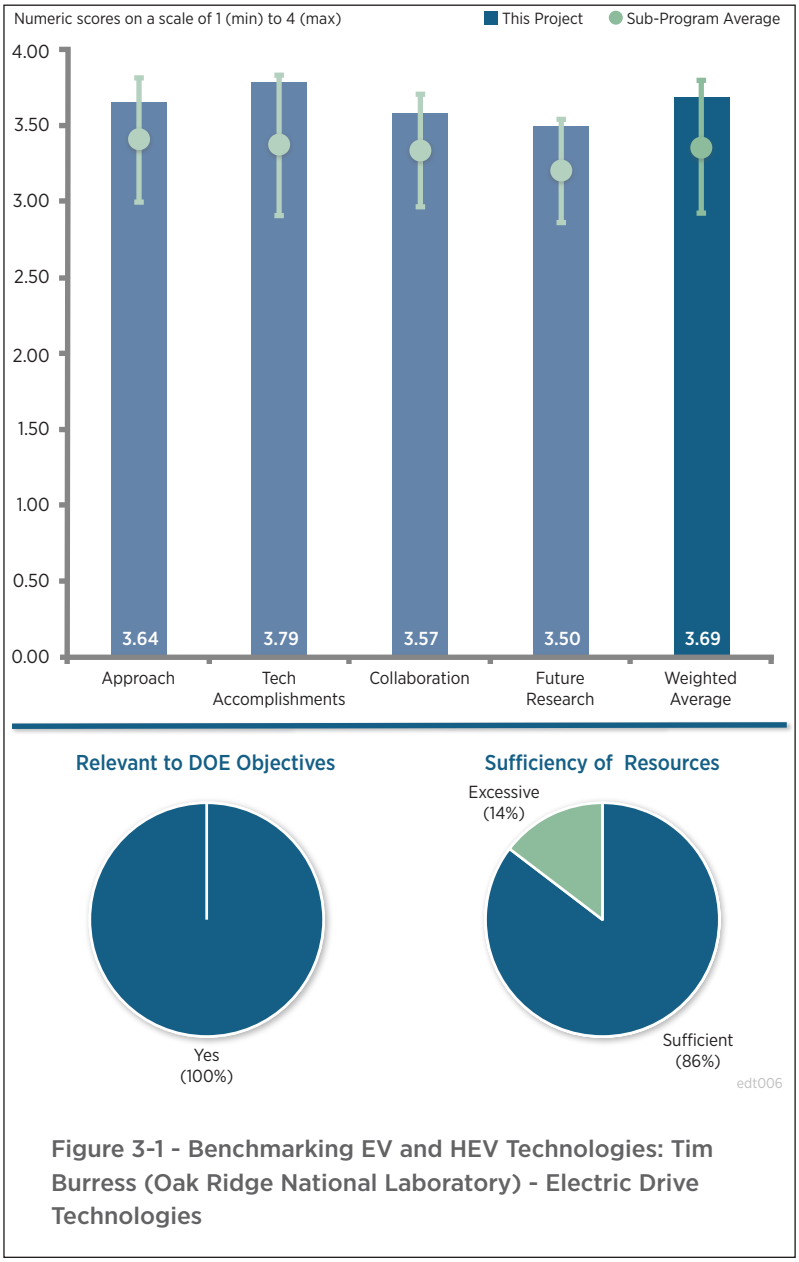

Figure 3-1 - Benchmarking EV and HEV Technologies: Tim Burress (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 3:
The reviewer acknowledged that this project provides a resource to U.S. researchers to help them understand the state of the commercial art.

Reviewer 4:
This reviewer stated that the approach to baseline the system with the same controls allows some standardized comparisons between systems. This person noted there should be some standard tests/metrics to try and level the systems such as long term continuous power capability (i.e., two hours plus), instead of just manufacturer's specifications. The reviewer expressed it would also be very relevant and useful to check the devices out as a system using the manufacturer's controls. This person pointed out the manufacturer may be trading off efficiency on one component (i.e., the motor), but getting better efficiency with the combination of moto , inverter, and controls. At a minimum this reviewer remarked the project should spot check a few data points with the manufacturer's controls, even if it is not a full duplication of the characterization.

Reviewer 5:
The reviewer praised the approach as a logical method that should lead to detailed knowledge of the selected

system. This person noted the high level description of the selection process was fine; howeve , how the final decision was made as to which two vehicles were selected in this case lacks detail. The reviewer remarked the vehicle testing followed by the tear down analysis was excellent; however, the reviewer suggested it would be beneficial to have a ruler or some other method of providing a size guide in the photos as well as some correlation between the vehicle performance testing and what is seen on the dyno testing. This person acknowledged that the motor controls used for the dyno testing may not be the same as those used in the vehicle.

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

Reviewer 1:
The reviewer confirmed the benchmarking work is detailed and impressive as was finding the new hardwar designs and performance of the two vehicle models under benchmark.

Reviewer 2:
This reviewer stated the program is effectively validating and testing manufacturer's known specs and characterizing the unknown performance.

Reviewer 3:
The reviewer remarked that results from the remaining tests on the 2014 Honda Accord were presented, along with initial results on the 2016 BMW i3. This person found the efficiency plots and details on motor and inverter construction methods very helpful.

Reviewer 4:
This reviewer confirmed the Honda Accord was nearly done, and the BMW i3 was in progress, which appeared on track. For the Honda Accord, this person suggested that the report include data on the boost direct current (DC/DC) such as inductor size, core, and DC-DC converter efficiency measurements

Reviewer 5:
The reviewer claimed the progress was very good, noting that trying to re-engineer a control/communication system is not a simple task nor is adapting a motor from a transmission into a housing suitable for dyno use. This person observed that the comparison chart continues to grow as new vehicles are tested and added. The reviewer suggested it might be interesting to provide a chart comparing and showing the changes to the Prius system/ performance from the earliest to the latest as well as a quick comparison to the other Toyota vehicles. While the task appears concentrated on the performance of the electrical propulsion system and the various technologies used in it, the reviewer pondered other aspects of the system/vehicle performance, such as EMC performance of the vehicle, and asked whether it meets Federal Motor Vehicle Safety Standards (FMVSS) standards or are performed as part of the vehicle testing. The reviewer also had questions about the analysis and whether any of it has been performed showing the benefits of the various cooling system designs in terms of reliability or junction temperatures over the various drive cycles tested.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated there is good collaboration with Argonne National Laboratory (ANL), National Renewable Energy Laboratory (NREL), Electrical and Electronics Tech Team (EETT), and the U.S. DRIVE Vehicle Systems Analysis Tech Team (VSATT).

Reviewer 2:
The reviewer noted the degree of collaboration seems appropriate for this project.

Reviewer 3:
This reviewer acknowledged the team has improved its workflow in response to reviewer comments

Reviewer 4:
This reviewer recognized that the results indicate that the collaboration between the team members/organization seems to be working very well. The person offered a comparison of the Oak Ridge National Laboratory (ORNL) component performance data to that taken at the vehicle level would help show the level of collaboration as well as the impact of the components on the overall vehicle's performance. This person wondered if data are available related to the types of materials used in the construction of the chassis and how it performs in the field, in terms of corrosion resistance.

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

Reviewer 1:
This reviewer declared the BMW i3, the LEAF, and new Prius are good choices.

Reviewer 2:
The reviewer ascertained there is a plan to test additional systems such as the next-generation Prius. This person confirmed the specific vehicles have not been narrowed down, but there is a pla

Reviewer 3:
The reviewer indicated the BMW i3 will be the focus for the remainder of Fiscal Year (FY) 2016 while specific systems for FY 2017 and FY 2018 have not yet been determined.

Reviewer 4:
This reviewer confirmed the proposed future research continues the process of testing leading vehicles in the market place. This person pondered whether there are any plans for investigating start-stop systems or EVs or if this is project limited to just hybrids. The reviewer wondered if the interface methods/components are being investigated such as high-voltage (HV)/high current connectors.

Reviewer 5:
Continuing the question about the implementation of double-side cooled power modules, it will be useful to this reviewer to have quantifiable data or metrics showing the benefits and impacts of the packaging technology on th electric drive system.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer confirmed this work evaluates the performance and manufacturing methods of state-of-the-art EV and HEV systems. This person acknowledged that this project allows DOE to gauge how close the systems are to the DOE targets and provides insight into how manufacturers can reach those targets.

Reviewer 2:
This reviewer said that characterizing the technologies that exist helps to gauge the effectiveness of fuel reduction technologies. The person commented that characterization also helps to understand how much room there is left for improvement on these technologies or for example whether the fundamental limit has been approached.

Reviewer 3:
The reviewer confirmed this project is very relevant to what the competition is doing to solve basically the same issue. By comparing different model years of the same vehicle, this person suggested it should be possible to determine growth in the technology used as well as future trends when comparing the various vehicles. This

reviewer pointed out the work should be useful for planning future products and the technology required to successfully compete in the market place.

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

Reviewer 1:
This reviewer claimed the team definitely has the best facility in the United States to conduct the proposed work

Reviewer 2:
The reviewer confirmed the project seems to have sufficient resources to execut

Reviewer 3:
This reviewer expressed the project appears to have sufficient resources

Reviewer 4:
The reviewer concluded the resources on this project are sufficient based on the results achieved. This person cautioned whether any additional resources would significantly reduce the time required to perform the testing and analysis, but it might reduce the time required to prepare the units for testing in the ORNL lab by some small amount; however, it is probably not worth the cost.

Reviewer 5:
This reviewer suggested more resources might allow more and quicker teardowns. total of seven reviewers evaluated this project.

Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors: Iver Anderson (Ames Laboratory) - edt015

Presenter
Matt Kramer, Ames Laboratory

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

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

Reviewer 1:
This reviewer confirmed the emphasis on simulation and theoretical analysis was the right approach to address the technical barriers. The sample test results proved this approach effective.

Reviewer 2:
The reviewer indicated the project is being very systematic and doing the right things to understand the physics of the barriers. The work is well focused on what is needed to be done to advance the technology.

Reviewer 3:
The reviewer claimed the approach was well thought out and reasonable.

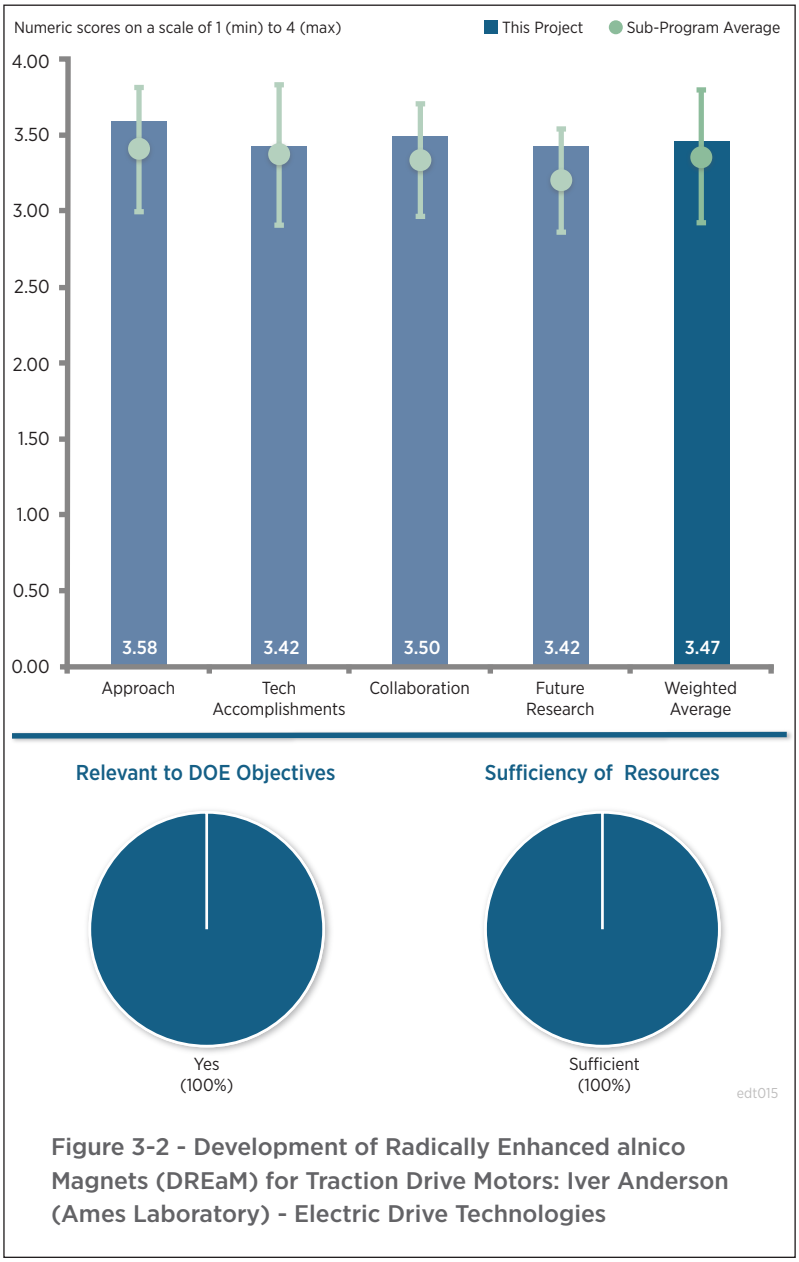

Figure 3-2 - Development of Radically Enhanced alnico Magnets (DREaM) for Traction Drive Motors: Iver Anderson (Ames Laboratory) - Electric Drive Technologies

Reviewer 4:
The reviewer observed great details in understanding magnet chemistry and their impact on the magnet physical properties.

Reviewer 5:
The reviewer said the team is taking a good approach focused on improved aluminum-nickel-cobalt (AlNiCo) as a replacement for RE permanent magnets (PMs) in traction motors. This reviewer wondered, though, if the goals are narrowly focused on the specific requirements of the UQM Technologies, Inc., motor. It appears, from industry comments at the review, that higher coercivity (4,000-4,500 Oersteds [Oe]) with high energy density may be required for practical applications. The reviewer suggested it will be good to show a line of sight to getting there, even if the current project does not attain these values.

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

Reviewer 1:
The reviewer commended the comprehensive multi-scale modeling in optimization of magnets as the major accomplishment, and noted it definitely serves the DOE goals by speeding up the magnetics improvements process

Reviewer 2:
The reviewer applauded model development to speed design as a welcomed accomplishment, providing fundamental insights. The synthesis of magnetic material demonstrates process understanding and control.

Reviewer 3:
The reviewer expressed the project is steadily improving the characteristics of AlNiCo magnets. There is a lot of great research being performed, and the progress made was at an appropriate level of technical detail. This person agreed the historical progression was well presented. Programmatically (that is reporting), the project indicated there were intermediate goals, but did not present what the intermediate goals were. The reviewer voiced that it appears there are multiple iterations being performed for optimization, but it is unclear how many iterations are expected and what timeline is expected for the intermediate steps. Verbally, the presenter indicated the end goal was an intrinsic coercivity (H_{ci}) of around 4,000-4,500, but it was unclear how long the project was expecting to get there (hard to track on a future timeline).

Reviewer 4:
The reviewer reinforced the team shared good progress, but it was not clear if the projected energy density with high coercivity has been obtained. It sounded like UQM will fabricate their motor with commercially available AlNiCo magnets. This reviewer cautioned this sounds like a lost opportunity to demonstrate the new magnets within an actual motor.

Reviewer 5:
This reviewer declared it is good that the team has been able to increase the coercivity of the proposed AlNiCo-based magnet materials for the past year. It would be good for the team to give a theoretical prediction on the maximum coercivity that the materials can eventually achieve. This person warned if the coercivity of the material cannot meet the requirements of automotive grade magnets, the risk of magnet demagnetization can be a major barrier to use these materials.

Reviewer 6:
This reviewer brought to light the marginal improvement in AlNiCo magnet's coercivity in the latest grade presented with respect to the last year's presentation. The target of greater than 2,500 Oe is still not enough to meet some of the less thermally challenged automotive applications.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer expressed there is excellent collaboration on this project that includes motor manufacturers, a magnet manufacturer (supplier), universities, ORNL, and NREL.

Reviewer 2:
This reviewer confirmed there was a comprehensive team with significant engagement from all partie

Reviewer 3:
This reviewer indicated good collaboration took place, although not much was addressed in the presentation, probably due to the time constraints.

Reviewer 4:
The reviewer mentioned the team appears to be collaborating broadly. One addition this reviewer recommended is to also consider partnering with motor developers that can take advantage of AlNiCo's high-temperature performance to reduce overall system level cost.

Question 4: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points,

considering barriers to the realization of the proposed technology and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
This reviewer commented the future path to advancing the technology is well thought out and very systematic. It is very likely the barrier issues will be overcome given enough time.

Reviewer 2:
This reviewer ascertained the team is clearly focused on the stated goals of achieving about a two times increase in energy density of AlNiCo at 180°C. The team feels confident this can be achieved by improving grain alignment and reducing the iron-cobalt (Fe-Co) needle diameters.

Reviewer 3:
The reviewer noted the remaining tasks are formulated well and the approach to overcoming the remaining barriers is clear.

Reviewer 4:
This reviewer declared Ames National Laboratory has a clear understanding of the need for improvements in coercivity of AlNiCo magnet. It will be very helpful in the future presentation if the magnetic hysteresis curve (B-H) of their latest grades are included and compared for various grade and Neo magnets. The reviewer suggested the tradeoffs between lower magnetic remanence (B_r) and higher coercivity should also be studied.

Reviewer 5:
The reviewer expressed concern over how this work results in a solution for automotive traction application with AlNiCo still so inferior to heavy RE magnets.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer claimed absolutely yes, as high-temperature and high-durability magnetic materials not requiring a special cooling is one of the greatest challenges in the electrical machine design.

Reviewer 2:
The reviewer explained this project is directly attacking a key barrier to cost effective traction motors by developing NRE magnets with competitive properties.

Reviewer 3:
The reviewer confirmed heavy RE material is the most expensive part of the moto . If AlNiCo grades have sufficient coercivit , then it may provide an alternate magnet solution to the motor designer to save cost in future designs.

Reviewer 4:
The reviewer confirmed this project focuses on an enabling technology (the material) that can help meet the performance objectives of DOE cost effectively.

Reviewer 5:
This reviewer stated this project tries to develop new AlNiCo-based magnet materials to be used on traction machines to reduce the dependency of foreign RE magnet materials.

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

Reviewer 1:
This reviewer observed the project has the right people assigned, and appears to be moving at a pace to achieve the goals.

Reviewer 2:
The reviewer noted there were no comments on the resources shortages; they seemed to be sufficient to accomplish the project goals.

North American Supply Chain for Traction Motors and PE: Christopher Whaling (Synthesis Partners) - edt032

Presenter
Christopher Whaling, Synthesis Partners

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

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

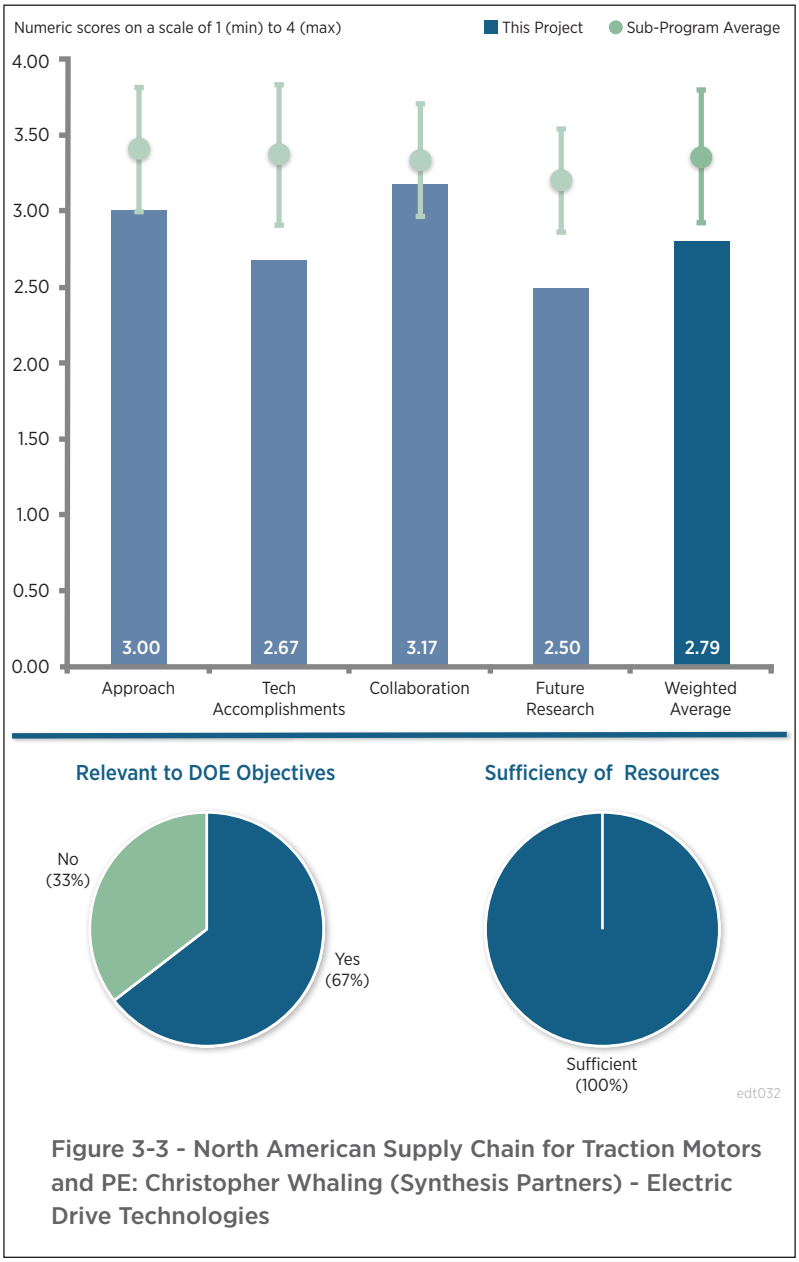

Figure 3-3 - North American Supply Chain for Traction Motors and PE: Christopher Whaling (Synthesis Partners) - Electric Drive Technologies

Reviewer 1:
This reviewer characterized the efforts in conducting interviews with North American (NA) suppliers and OEMs to understand the gaps in the supply chain as good.

Reviewer 2:
The reviewer found the approach to collect information reasonable, but the project lacks a clear method of analyzing the data.

Reviewer 3:
The reviewer asserted this project is unlike the other projects on the deck with respect to technical content. While the reviewer understood the goals and the importance of investigating potential challenges with the NA supply chain for traction motors and PE, this person found it hard to assess the validity of the approach. Synthesis Partners likely has a tried and tested method to gather and analyze market intelligence in a rigorous manner, but it is not clear to this reviewer how the collected information can be validated. The reviewer questioned how sampling bias is avoided.

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

Reviewer 1:
This reviewer agreed the study showed clear technological gaps in the NA supply chain for motors and PE.

Reviewer 2:
The reviewer noted the team gathered information that shed light on important questions. This person would recommend probing more deeply into some of the points raised by vendors. For example, lack of strategic investment planning/situational awareness has been highlighted as a major barrier. The reviewer suggested it will

be good to understand how much of this can be attributed to a lack of vision from business leaders and corporate averseness to risk, versus a reaction to a lack of strategic plan by the nation.

Also, this reviewer asserted it will be good to see areas where a lack of core competencies and/or technology are the bottlenecks, in addition to economics driven challenges.

Reviewer 3:
The reviewer observed the information presented was too general and there was a lack of actionable data provided. This person suggested a need to be more specific of how or what should be done

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer commented the work was done with a wide variety of industry participants.

Reviewer 2:
This reviewer cautioned some notable vendors were not highlighted in the example lists shared. The person suggested it will be good to review how the vendors being interviewed are selected and are representative of the breadth of the industry.

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

Reviewer 1:
The reviewer concluded continuing the interviews, understanding the gaps, and informing VTO officials will be helpful in directing attention where needed to bridge the gaps.

Reviewer 2:
This reviewer suggested the project explore the possibility of proactively reaching out to a broader set of vendors that are representative of the industry.

Reviewer 3:
This reviewer expressed that analysis needs to be performed on the information already collected to derive conclusions that can be acted on. Asking further questions as described in future work would not provide value at this time.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer expressed having strong and robust supply base in NA provides cost savings for manufacturing motors and PE components for NA applications.

Reviewer 2:
The reviewer summarized that this is a good area of work, but the project currently is not providing tangible and actionable information. Actionable information should show what needs to be done and provides a recommendation of what action should be carried out to address needs.

Reviewer 3:
This reviewer reported that while this is an important activity, it has more do to with having manufacturing capability and jobs in the United States rather than on petroleum displacement.

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

No comments were received in response to this question.

Advanced Packaging Technologies and Designs: Zhenxian Liang (Oak Ridge National Laboratory) - edt049

Presenter
Zhenxian Liang, 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:
This reviewer summarized the approach as prototyping of a power module to demonstrate that WBG devices and chipsets can indeed be packaged in the form of a half-bridge power module.

This person stated 3D printing to manufacture heat-sink and power module case is utilized.

The reviewer recounted the method for WBG power device package optimization is described and benefits of optimized package is documented in the project report.

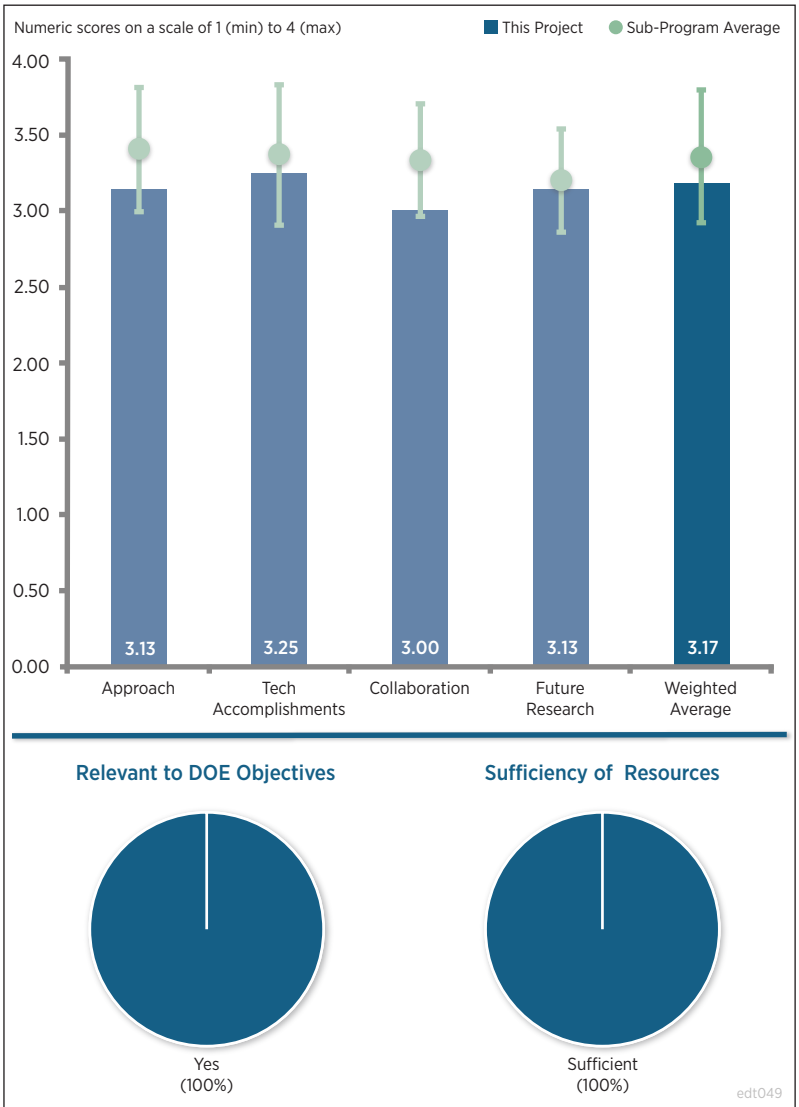

Figure 3-4 - Advanced Packaging Technologies and Designs: Zhenxian Liang (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 2:
The reviewer observed that the approach seems to be; package a half bridge between two substrates; Planar-Bond-All (PBA) components within the bridge with attached heat sink coolers; use modeling, prototyping and evaluation to guide and validate the approach over time. This person suggested it would be useful to see a listing of the challenges related to the PBA packaging approach.

Reviewer 3:
The reviewer said there was relevant direction, but the approach appears to be somewhat behind what industry is doing and from some other presentations at this AMR.

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

Reviewer 1:
This reviewer recounted the accomplishments: packaging process for power module is developed; 300 amperes (A)/1,200 Volt (V) power module packaged and successfully used in air-cooled inverter; parasitic inductance of power module is reduced by 75% by layout optimization for WBG chipsets; benefits of laminated and planar structure of inverter power stage demonstrated; and solver sintering is used in module packaging.

Reviewer 2:
The reviewer stipulated some progress was made in silver (Ag) die attach and in reduction of loop inductances, but cautioned the inductances need to be further reduced.

Reviewer 3:
The reviewer applauded the modeling of the electrical parasitics as excellent, and noted this helps with the electrical layouts. This person questioned whether it would be possible to share more model results for the overall mechanical package including a thermo-mechanical model for the overall package that gives an indication that the PBA package will hold together under thermal stress. This will help to support the goal of a highly reliable integrated SiC module prototype. The reviewer wondered, with a system that is called PBA, why there are wire bond interconnects.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer reinforced the project has the right team of people working. It would be helpful to know what reliability tests the partners are asking for in order to verify the design. This person questioned if the PBA approach considered a power module, and if so, if it is tested as a power module using Automotive Electronics Council (AEC) Q101 tests. Additionally, the reviewer wondered if it is not a power module what tests are being used to validate the design and predict its high reliability.

Reviewer 2:
This reviewer offered that the team would benefit from industrial collaborators who would actually use the results

Reviewer 3:
This reviewer warned that the Principal Investigator (PI) is collaborating with part suppliers while collaboration with end user is absent. It is recommended that an industry partner is identified and the PI should work closely with industry toward objectives such as U.S. manufacturing and technology commercialization pathway.
This person cautioned the technology to market and commercialization pathway is absent.

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

Reviewer 1:
The reviewer expressed that the development of high-temperature power modules and their integration in inverter fed motor control system is stated as future research work, which could somehow provide some sort of pathway towards commercialization.

Reviewer 2:
The reviewer wondered when the thermo-mechanical analysis comes into play and would like to see life test results for the overall package, not just die attach after the PBA module has undergone life testing.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer reinforced that WBG PE know-how produced at ORNL will indirectly benefit industry and make a case for adoption by automotive industries.

Reviewer 2:
The reviewer indicated if the project can show it meets the DOE 2022 targets, it is an enabler for lower cost PE, which will expand the market for EDVs and reduce our dependence on foreign oil.

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

Reviewer 1:
This reviewer concluded the project has the right team of industry and labs.

Electric Drive Inverter R&D: Madhu Chinthavali (Oak Ridge National Laboratory) - edt053

Presenter
Madhu Chinthavali, Oak Ridge National Laboratory

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

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

Reviewer 1:
This reviewer mentioned multiple activities are being performed on the project and there is excellent dissemination of data for the benefit of the technical community.

Reviewer 2:
The reviewer expressed the approach to bench line existing converters, build one with the same components, build an improved one, then modify to find better methods or optimize as a sound one.

Reviewer 3:
The reviewer considered that this project aids the R&D of the electric drive inverter in the United States.

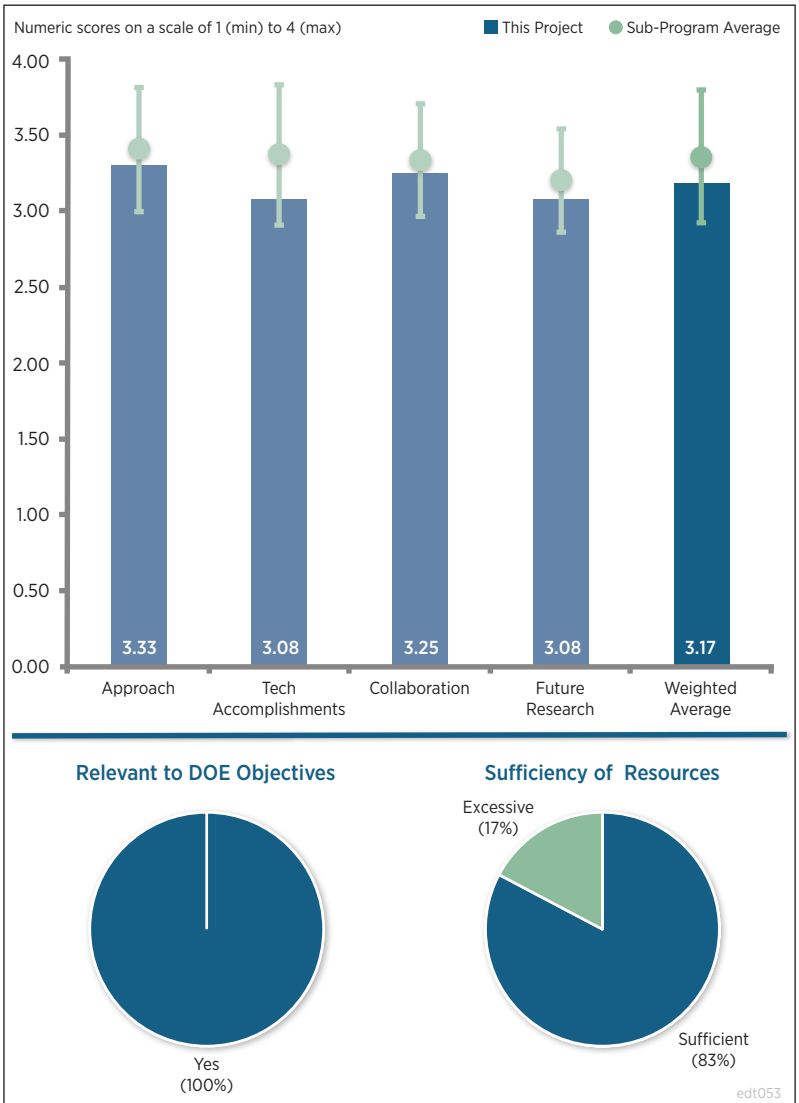

Figure 3-5 - Electric Drive Inverter R&D: Madhu Chinthavali (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 4:
The reviewer recounted the approach as testing of various WBG devices supplied by manufacturers, apparently to verify data sheet parameters followed by a trench metal–oxide–semiconductor (MOS) this year. This approach appears more directed at performing double pulse tests, rather than demonstrating new approaches to WBG PE to meet APEEM targets.

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

Reviewer 1:
The reviewer observed that the testing and simulation results look very promising and it appears there is good progress being made. Some of the test results had temperatures (test conditions) listed, but it would be helpful if all reported tests (and simulations) had the ambient and coolant temperatures clearly stated.

Reviewer 2:
This reviewer declared that the team has performed significant work on gate drive design, module layout, and overall system layout. The person suggested the overall system layout also incorporate structural analysis to accommodate typical vibration seen in automotive inverters.

Reviewer 3:
The reviewer judged that the technical accomplishments and progress were on track, but more innovations are necessary to meet the 2022 power density requirement.

Reviewer 4:
This reviewer concluded that compared with other projects, this one appears to be substantially behind. It is true that WBG gate drivers can be challenging, but there are many examples in the literature, industry, and other AMR projects that work. The person noted that efforts to achieve 100 kilohertz (kHz) experimental switching frequency, power density, etc., have been unsuccessful so far because of layout and noise issues. The reviewer concluded if the experimental setup does not work, then testing of devices is suspect. Perhaps the team could benefit from using evaluation kits from GE, Cree, Transphorm, etc.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer offered that the team has excellent connections with manufacturers for devices and passive elements.

Reviewer 2:
The reviewer considered all the partners have contributed to this work.

Reviewer 3:
This reviewer recounted that collaboration is summarized as a list of WBG device and capacitor vendors.

Reviewer 4:
The reviewer emphasized that this project is focused on methods, rather than specific hardware transition, so manufacturability does not fully come into play, but it may be helpful to have an OEM as a collaborator to give an end user/integrator/manufacture perspective.

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 specified that the design and testing of the inverter design would be a good accomplishment. The test results would enable the community to evaluate the benefits of WBG devices.

Reviewer 2:
This reviewer described the future research as good overall, but some of the barrier issues such as capacitor volume and lower parasitic inductance are not listed as research items. These appear to be needed to achieve the goals, so there should be some time dedicated to these barriers.

Reviewer 3:
This reviewer wondered what the optimization target was with the current simulated parasitic inductance below five nanohenries (nH). The reviewer further questioned to what frequency range the reduced parasitic inductance will increase, if this target has been met.

Reviewer 4:
The reviewer highlighted that it would be good to pay attention in the upcoming tests if the use of WBG PE causes any concerns on reflected wave phenomenon

Reviewer 5:
To this reviewer, it is not clear how the investigators will overcome their gate driver problems so that the team can address APEEM targets.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
This reviewer reinforced that this project helps provide approaches to meeting the DOE cost and power density goals. The research into a smarter gate control and incorporating 3D printing to optimize utilization of devices and space claim will help drive the end result.

Reviewer 2:
The reviewer agreed that the WBG inverter would support the objectives of 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 considered the project to be resourced and funded appropriately.

Reviewer 2:
This reviewer pointed out that the resources appear to be sufficient to accomplish the goals

Innovative Technologies for Converters and Chargers: Gui-Jia Su (Oak Ridge National Laboratory) - edt054

Presenter

Gui-Jia Su, 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:

This reviewer expressed this was a novel approach that incorporates WBG devices, planar magnetics, and up-to-date converter topologies.

This reviewer affirmed combining or the sharing of components to increase the overall power density and targeting lower system cost is a good approach.

Reviewer 2:

The reviewer claimed that a high power density integrated charger will be required by the automotive industry and this project is addressing issues associated with this technology. This person recognized the proposed topology of the power converter used in integrated charger and inverter systems uses fewer components and takes advantages of WBG devices.

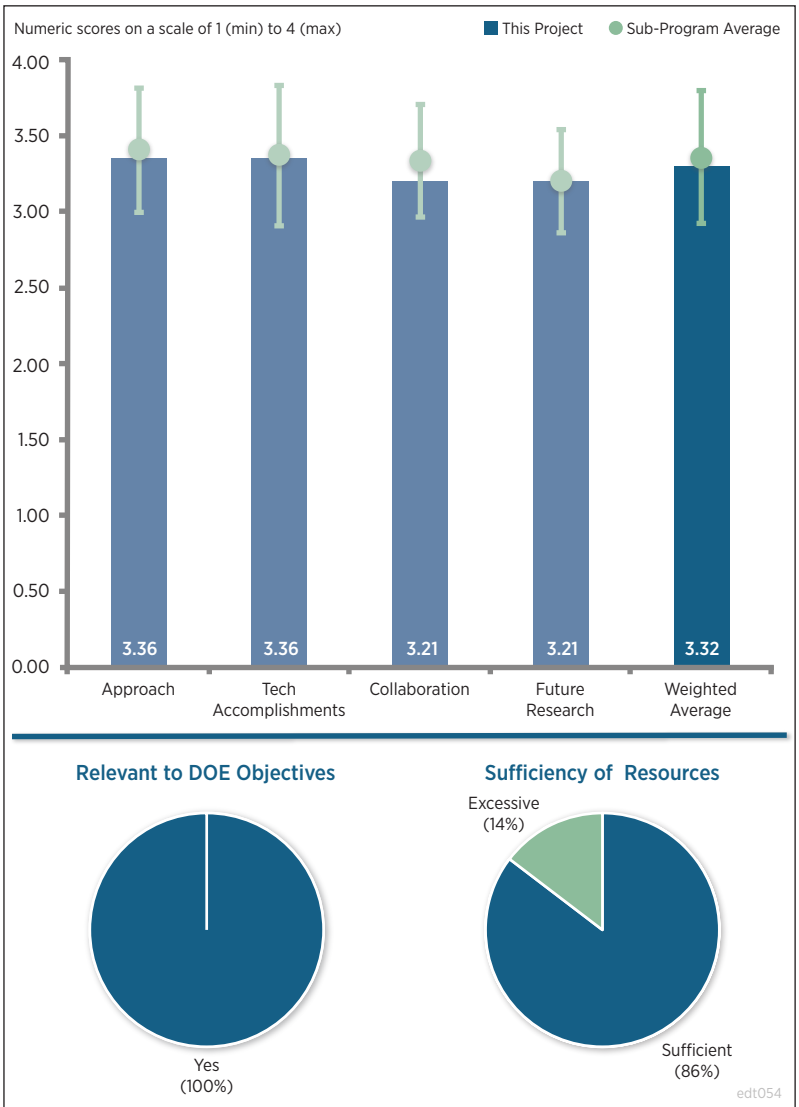

Figure 3-6 - Innovative Technologies for Converters and Chargers: Gui-Jia Su (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 3:

The reviewer claimed the approach is to focus on high switching frequencies and 3D printing of components to reduce the space claim and weight. The project appears to be moving forward, but it would help if there were a more systematic approach defined to help keep things on track. The presentation indicated more work was needed on the 3D printing, but did not expand on what the plan forward was.

Reviewer 4:

This reviewer pointed out the proposed charging solutions are only single phase and need access to the neutral point of the motor. Even though bringing out the neutral might not be very costly, it would have potential reliability issues.

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

Reviewer 1:
This reviewer expressed that an interesting contribution of this work is the lightweight, low-loss nano-magnetic powder material and printed E-core manufacturing.

Reviewer 2:
This reviewer claimed the team's charger comparison to the Nissan LEAF charger is a good comparison as well as showing the project is on the right path. Use of the 3D printed cold plate and E-core is a good approach to advancing additive manufacturing. Now that the project can print magnetics, this person questioned why it was limited to a traditional E-core rather than something that is more space efficient. The reviewer concluded the progress appears to be on track.

Reviewer 3:
This reviewer declared the Dual Active Bridge design using GaN and planar magnetics has led to good experimental results in both efficiency and power densit . The printed magnetic core was unsuccessful.

Reviewer 4:
The reviewer explained that SiC and silicon (Si) on-board chargers (OBC) are compared for efficiency over load in the range from 1 kilowatt (kW) to 6 kW. It is demonstrated that the Si-based charger runs into limit for load power greater than 6 kW. This reviewer also noted the following: 6.6 kW SiC OBC built and tested; GaN devices are characterized, such as double pulse testing and GaN H-bridge circuit tested; GaN H-bridge circuit's efficiency over voltage and frequency range is measured; design of GaN based 6.6 kW OBC is completed, including planar magnetics needed on OBC; magnetic cores are printed at ORNL; and NREL did thermal analysis of OBC in computational fluid dynamics (CFD) analysis using pin-fin heat-sin

Reviewer 5:
The reviewer agreed the 3D printed heat sink has great promise for targeted heat rejection with minimal materials. The 3D printed inductor slightly increases inductance over an open air inductor, but is a long way away from the inductance of a traditional iron core inductor. This person explained the presentation did not elaborate what benefit there was to using the printed core (other than an implied slight decrease in size). With some work still needing to be done on packaging, it is unclear to this reviewer why there is a push to integrate with a traction drive on schedule. It seems the GaN converter should be optimized a bit more prior to integration.

This person emphasized there are not clear milestones as compared to the DOE goals for power density. The chart that compares the LEAF to the ORNL charger is helpful, but does not directly show the path to get to the DOE goals. The reviewer offered that milestones and a timeline be added to help track the progress of the project. The project should report both coolant and ambient temperatures at which the devices are being tested. This person wondered whether temperature reported was room temperature or vehicle under-hood temperatures with engine temperature coolant. In order to be relevant to the DOE goals, the project should be focused on the end vehicle installation temperatures.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer concluded the project includes collaboration with vendors but not with OEMs or Tier 1 suppliers who would use the results.

Reviewer 2:
The reviewer claimed the project has good representation from the component supplier base, but would benefit from an OEM or end manufacturer. A manufacturer/OEM would help transition the product, bring insight into the manufacturability of the product, and provide a transition path.

Reviewer 3:
This reviewer would like to see an auto industry partner or collaborator.

Reviewer 4:
This reviewer acknowledged the PI is collaborating with part and engineering service suppliers, such as NREL, GaN Systems, ROHM, Aegis Tech, and Ferroxcube USA. Collaboration with end user industry is absent, and so the path to commercialization and U.S. manufacturing is also absent.

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 declared the future research as an appropriate plan for completion of work.

Reviewer 2:
The reviewer recounted that GaN-based isolated converter and its integration with SiC traction drive are identified as future research work to demonstrate feasibility of all WBG OBC systems.

Reviewer 3:
The reviewer observed focus on meeting project objectives.

Reviewer 4:
This reviewer observed the future research jumps directly to integration of the converter without optimizing the converter. A level of integration is good to see what else needs to be done in the converter design, but it seems the research should focus on getting to the DOE power density goals prior to advancing to the next step.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
This reviewer affirmed this project supports the overall DOE objectives. Having low cost, power dense electronics enables fuel savings through electrification

Reviewer 2:
The reviewer acknowledged the team is trying to enhance efficiency and power densit .

Reviewer 3:
This reviewer noted the WBG PE research aligns with DOE objectives.

Reviewer 4:
The reviewer observed that if the project can show it meets the DOE 2022 targets, it becomes an enabler for lower cost PE, which will expand the market for EDVs and reduce our dependence on foreign oil.

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

Reviewer 1:
The reviewer indicated the resources appear to be sufficient and appropriate for the project

Reviewer 2:
The reviewer said the project has the right team of both industry and labs; however, this person would like to see an auto industry collaborator.

Advanced Low-Cost SiC and GaN Wide Bandgap Inverters for Under-the-Hood Electric Vehicle Traction Drives: Kraig Olejniczak (Wolfspeed) - edt058

Presenter
Kraig Olejniczak, Wolfspeed

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:
This reviewer mentioned multiple activities are being performed on the project and there is excellent dissemination of data for the benefit of the technical community.

Reviewer 2:
The reviewer expressed the approach to bench line existing converters, build one with the same components, build an improved one, then modify to find better methods or optimize as a sound one.

Reviewer 3:
The reviewer considered that this project aids the R&D of the electric drive inverter in the United States.

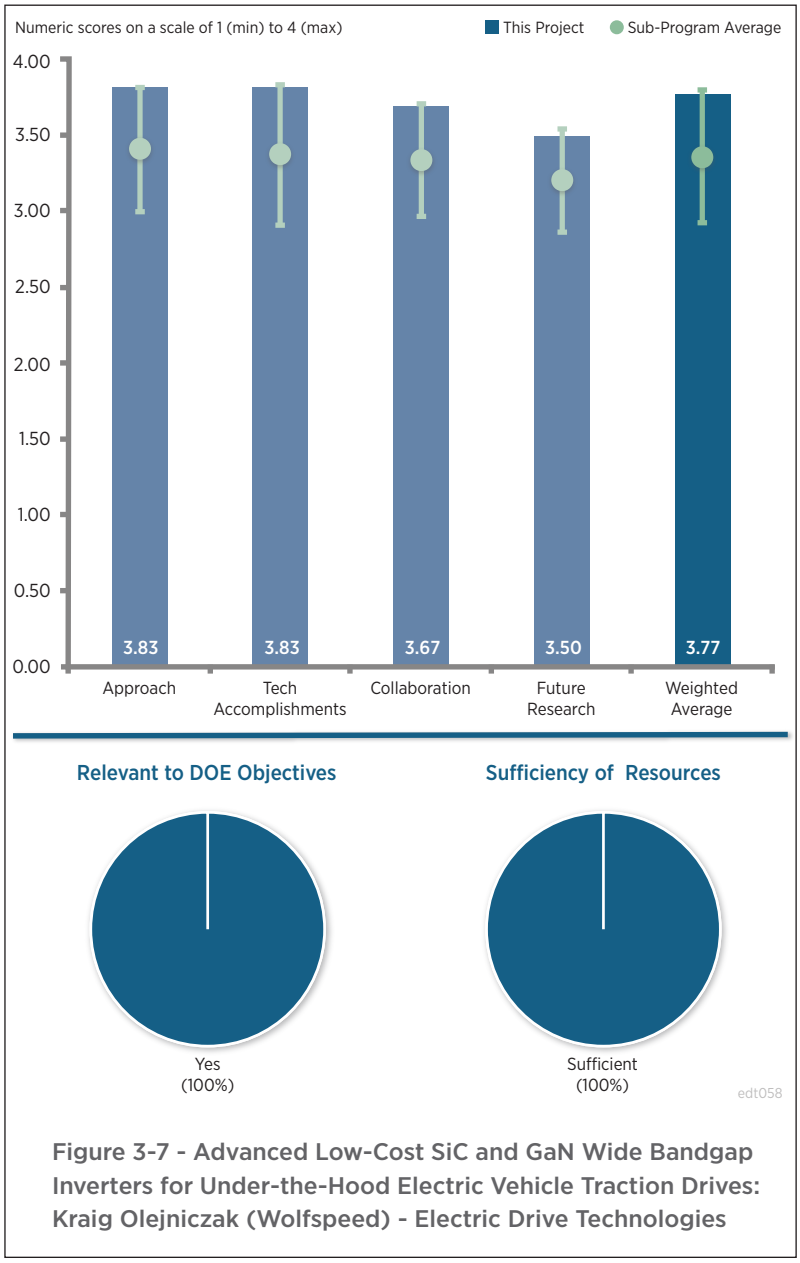

Figure 3-7 - Advanced Low-Cost SiC and GaN Wide Bandgap Inverters for Under-the-Hood Electric Vehicle Traction Drives: Kraig Olejniczak (Wolfspeed) - Electric Drive Technologies

Reviewer 4:
The reviewer recounted the approach as testing of various WBG devices supplied by manufacturers, apparently to verify data sheet parameters followed by a trench metal–oxide–semiconductor (MOS) this year. This approach appears more directed at performing double pulse tests, rather than demonstrating new approaches to WBG PE to meet APEEM targets.

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

Reviewer 1:
The reviewer observed that the testing and simulation results look very promising and it appears there is good progress being made. Some of the test results had temperatures (test conditions) listed, but it would be helpful if all reported tests (and simulations) had the ambient and coolant temperatures clearly stated.

Reviewer 2:
This reviewer declared that the team has performed significant work on gate drive design, module layout, and overall system layout. The person suggested the overall system layout also incorporate structural analysis to accommodate typical vibration seen in automotive inverters.

Reviewer 3:
The reviewer judged that the technical accomplishments and progress were on track, but more innovations are necessary to meet the 2022 power density requirement.

Reviewer 4:
This reviewer concluded that compared with other projects, this one appears to be substantially behind. It is true that WBG gate drivers can be challenging, but there are many examples in the literature, industry, and other AMR projects that work. The person noted that efforts to achieve 100 kilohertz (kHz) experimental switching frequency, power density, etc., have been unsuccessful so far because of layout and noise issues. The reviewer concluded if the experimental setup does not work, then testing of devices is suspect. Perhaps the team could benefit from using evaluation kits from GE, Cree, Transphorm, etc.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer offered that the team has excellent connections with manufacturers for devices and passive elements.

Reviewer 2:
The reviewer considered all the partners have contributed to this work.

Reviewer 3:
This reviewer recounted that collaboration is summarized as a list of WBG device and capacitor vendors.

Reviewer 4:
The reviewer emphasized that this project is focused on methods, rather than specific hardware transition, so manufacturability does not fully come into play, but it may be helpful to have an OEM as a collaborator to give an end user/integrator/manufacture perspective.

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 specified that the design and testing of the inverter design would be a good accomplishment. The test results would enable the community to evaluate the benefits of WBG devices.

Reviewer 2:
This reviewer described the future research as good overall, but some of the barrier issues such as capacitor volume and lower parasitic inductance are not listed as research items. These appear to be needed to achieve the goals, so there should be some time dedicated to these barriers.

Reviewer 3:
This reviewer wondered what the optimization target was with the current simulated parasitic inductance below five nanohenries (nH). The reviewer further questioned to what frequency range the reduced parasitic inductance will increase, if this target has been met.

Reviewer 4:
The reviewer highlighted that it would be good to pay attention in the upcoming tests if the use of WBG PE causes any concerns on reflected wave phenomenon

Reviewer 5:
To this reviewer, it is not clear how the investigators will overcome their gate driver problems so that the team can address APEEM targets.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
This reviewer reinforced that this project helps provide approaches to meeting the DOE cost and power density goals. The research into a smarter gate control and incorporating 3D printing to optimize utilization of devices and space claim will help drive the end result.

Reviewer 2:
The reviewer agreed that the WBG inverter would support the objectives of 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 considered the project to be resourced and funded appropriately.

Reviewer 2:
This reviewer pointed out that the resources appear to be sufficient to accomplish the goals

High Temperature DC-Bus Capacitor Cost Reduction and Performance Improvements: Angelo Yializis (Sigma Technologies International) - edt059

Presenter
Angelo Yializis, Sigma Technologies International

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 emphasized that this project has demonstrated a very novel approach to produce film capacitors and the results obtained are very impressive.

Reviewer 2:
The reviewer summarized the main approach of this work is to scale-up a liquid/vapor deposition process for polymer-metal multilayer capacitors. Sigma has established equipment and processes for synthesizing thin layers of high-temperature polymers, which are important for capacitors operating in an electric vehicle. This person noted the novel process allows for sub-micron films to be fabricated. Conventional extrusion processes are currently limited to above three microns in high-temperature polymer systems. The energy density will increase as thickness decreases for the 450 V electric vehicle application.

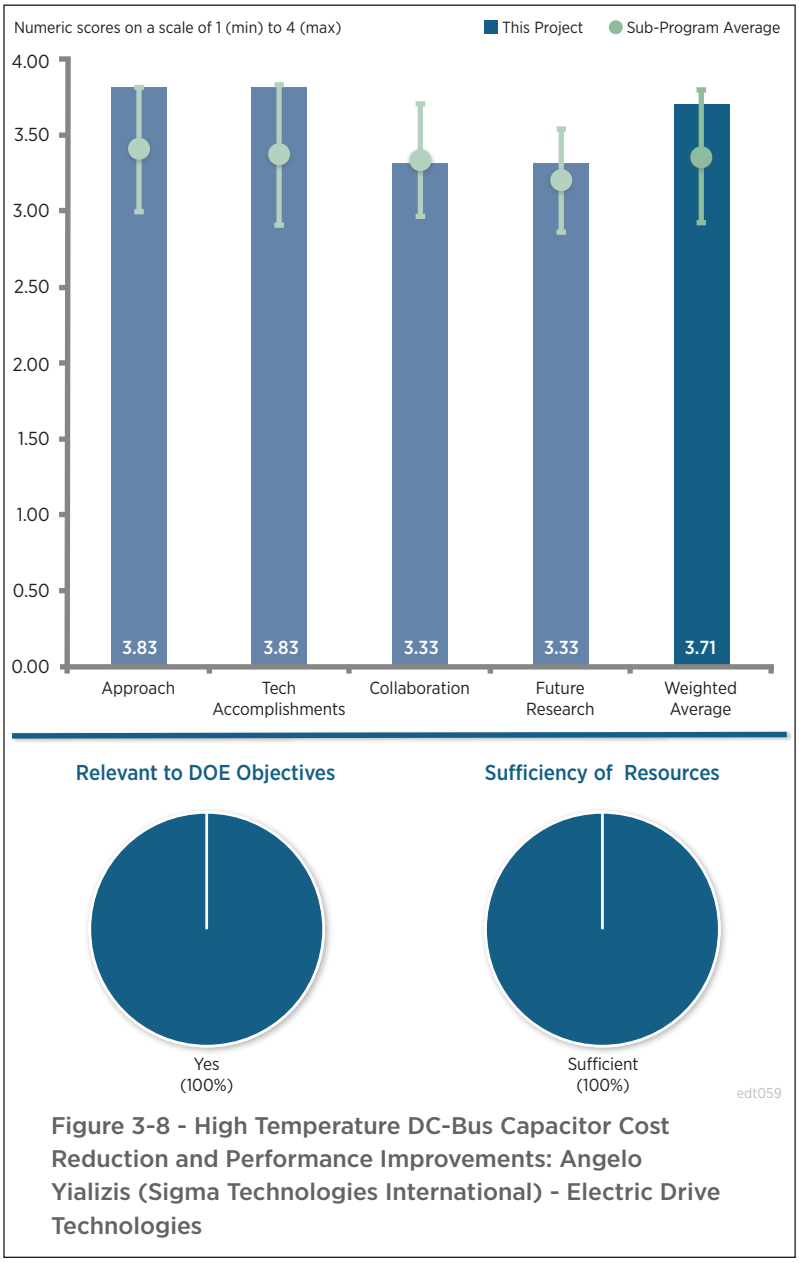

Figure 3-8 - High Temperature DC-Bus Capacitor Cost Reduction and Performance Improvements: Angelo Yializis (Sigma Technologies International) - Electric Drive Technologies

Reviewer 3:
This reviewer expressed the research of this project is to engineer a capacitor that could overcome limitation of polypropylene capacitor. As per Sigma Technologies, liquid monomer and aluminum wire are converted in a single step into Mother Capacitor material, which become building block polymer-multi-layer (PML) capacitor. This person noted there is a new electrode mask which doubles the number of capacitors produced in a single run. Elimination of specialized termination needed for electrical connection could help reduce cost and increase micro Farad/Liter. Passivation of aluminum electrodes prevents corrosion and hence could enhance life and reliability of PML capacitors.

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

Reviewer 1:
This reviewer mentioned outstanding results and prototype hardware built so far has clearly exceeded DOE goals. Test results shown in the presentation meet the requirements and the team is requested to perform rigorous reliability testing.

Reviewer 2:
This reviewer expressed prototype parts produced and sent off to Delphi for characterization can be stated as a major success of this project. The U.S. manufacturing and commercialization pathway is not clear.

Reviewer 3:
This reviewer indicated the DOE targets for the DC bus capacitor are related to operation temperature and reliability and all these issues are being addressed by the work. Specificall , 700 microfarad capacitors have been fabricated with sizes that are significantly smaller than the capacitors that are currently used in electric vehicles. High energy densities have also been demonstrated in thin (0.5 micron) materials. This person pointed out a typographical error on Slide 10 where units should be microns not millimeters (mm) and a typographical error on Slide 19 that should be milliohms.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer declared very good collaboration with Delphi to evaluate the reliability of the parts. Depending on the remaining budget, the team is requested to provide samples to other key organizations in the vehicle technologies space to jumpstart development and foster incorporation of this capacitor technology into product designs.

Reviewer 2:
This reviewer stated the PI is collaborating with Delphi.

Reviewer 3:
This reviewer assessed that a majority of the work was done at Sigma. ORNL is collaborating on the thermal mechanical modeling but no results were shown in the presentation. Delphi is working on the potting process for capacitor arrays.

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

Reviewer 1:
This reviewer offered reliability evaluation is key in gaining confidence in this technolog . The team is requested to share the results through presentations in conferences and papers. This would enable a stronger pull to adopt this capacitor concept into product designs.

Reviewer 2:
This reviewer recounted the focus is on cost and commercialization plan. The technical plan is to integrate these capacitors with an inverter.

Reviewer 3:
This reviewer expressed the AEC Q200 qualification is planned and it could help PM capacitor adoption

in automotive applications. It would be nice if the developed technology is commercialized soon and finds applications in automotive and industrial applications.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:

This reviewer explained capacitor size reduction is key to increase the power density of PE for electric hybrid vehicles. This effort is clearly tied to DOE goals in this area.

Reviewer 2:

This reviewer offered that high-temperature capacitors are needed for WBG PE, which is essential for petroleum displacement due to efficiency gains possible

Reviewer 3:

This reviewer indicated the project directly addresses the system cost and performance of EDVs. Higher temperature capacitors will result in lower cooling requirements for the power converters and hopefully the cooling systems can be eliminated.

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

Reviewer 1:

The reviewer judges the financial support is sufficient for the capacitor development, prototyping, an characterization efforts.

High-Performance DC Bus Film Capacitor: Dan Tan (General Electric) - edt060

Presenter
Dan Tan, General Electric

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 specified the main objective of this work is to develop high-temperature polymer films for DC bus capacitors. Specificall , polyetherimide (PEI) films are being explored because this polymer has excellent high-temperature dielectric performance. This person noted there are several important criteria that must be achieved before this material can be commercialized for electric vehicle applications. The DOE targets for the DC bus capacitor are related to operation temperature, cost, and reliability, and all these issues are being addressed by the work.

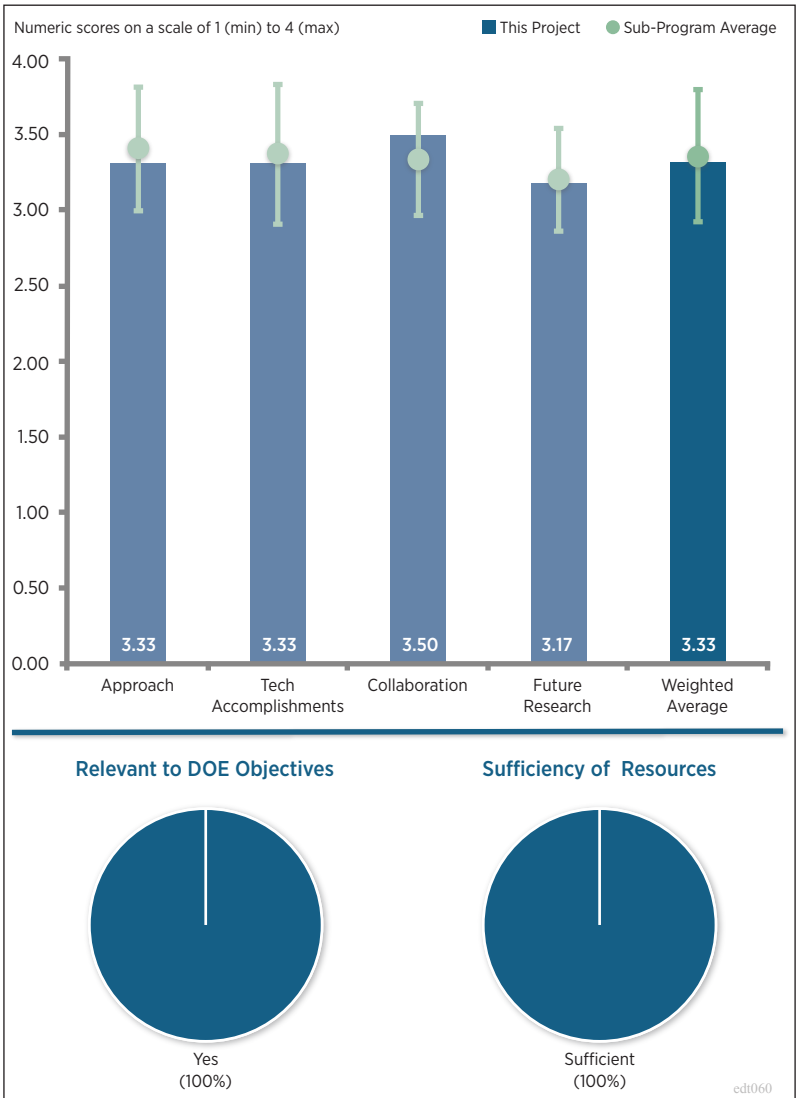

Figure 3-9 - High-Performance DC Bus Film Capacitor: Dan Tan (General Electric) - Electric Drive Technologies

Reviewer 2:
This reviewer declared high-temperature extruded polymer film could result in higher packing density parts, particularly for application voltages greater than 800 V, provided V/micro-meter is properly engineered. The inorganic coating of PEI films increased breakdown voltage. Therefore, the coating can be advantageous; however, the process needs to be scaled for PEI film for all possible thickness

Reviewer 3:
This reviewer reported the team has overcome significant challenges to be able to put together the individual elements for the proposed capacitor. However, it appears as if the team still has multiple issues to deal with to meet the project milestones and deadlines. The reviewer expressed concern that the team will not be able to meet the milestones without further delays.

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

Reviewer 1:
This reviewer claimed the team has made significant progress; howeve , testing on the film dissipation factor (DF) and breakdown at elevated temperatures needs to be performed.

Reviewer 2:
This reviewer acknowledged there has been continued progress in decreasing the PEI film thickness over time, with over a 40% decrease in the last six years. This metric is very important for volumetric efficiency and cost. This person offered the process challenge is to create wrinkle-free films with a minimum number of surface defects. The process challenges become increasingly difficult for PEI films below four microns in thicknes

The roll-to-roll oxide deposition method shows promising results, but scale-up was shown to be difficult. The reviewer recounted the PI decided to stop development efforts on the coating. Self-healing was also explored under this program and a number of aluminum deposition parameters were surveyed. It was found that a specific sheet resistance range was required for self-healing.

The reviewer mentioned once the film is fabricated, there are many steps in capacitor manufacturing including winding, end terminations, and packaging. In addition to film resistance, higher equivalent series resistance (ESR) was also found after winding process. This person commented it was also interesting that the DF increased by an order of magnitude when the sheet resistance increased by two.

The reviewer ascertained there have been delays in delivering the large capacitor prototypes and pondered when these will be delivered for final testing

Reviewer 3:
This reviewer recounted that the 3.5 micrometer (μm) PEI film was produced by extrusion and the wrinkle-free PEI films scaled-up and are ready for capacitor prototyping. Film tested in oil and higher break-down voltage indicates that impregnation of PEI capacitor could be helpful for breakdown voltage and environment management, such as impregnation lending itself to prevent intrusion of humidity and moisture. This person noted roll-to-roll oxide coating was demonstrated on 5-μm PEI film. The U.S. manufacturing and commercialization pathway is not very clear.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer confirmed General Electric (GE) is collaborating with companies along the entire supply chain. At the materials level, GE is working with two film manufacturers that were unnamed. It appears that most of the GE effort is in the scale-up of the capacitor manufacturing and testing, so this is at the component level. Delphi provides the systems perspective.

Reviewer 2:
This reviewer highlighted the team appears to have reached out to multiple corporations to mitigate the schedule and technical challenges.

Reviewer 3:
This reviewer indicated that Ralph Taylor from Delphi is identified as collaborator in project report. PI did not put much emphasis upon any on-going collaboration for this project.

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

Reviewer 1:
The reviewer brought to light this is the last year of the program so finishing the prototype development is the most important future task. The 4-micron film will be used to fabricate the 700 microfarad capacitor bank

Reviewer 2:
This reviewer commented that some tasks are briefly stated and the PI did not put much emphasis upon future research.

Reviewer 3:
The reviewer declared the team has quite a few tasks remaining this year to complete the project. The person suggested the team ensure that the film quality and capacitor manufacturing process are carefully monitored to ensure no further delays.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
This reviewer affirmed the project directly addresses the system cost and performance of EDVs, which will significantly decrease the overall fuel consumption. Higher temperature capacitors will result in lower cooling requirements for the power converters and hopefully the cooling systems can be eliminated.

Reviewer 2:
The reviewer explained high-temperature film capacitors could enable successful realization and commercialization of WBG PE, which have far higher efficiency versus Si-based PE

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

Reviewer 1:
The reviewer offered the resources are sufficient and there is a significant cost match from the G Aerospace Division, which will probably be the first market for these high-temperature capacitors

Advanced Electric Motor Research: Tim Burress (Oak Ridge National Laboratory) - edt062

Presenter
Tim Burress, 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.

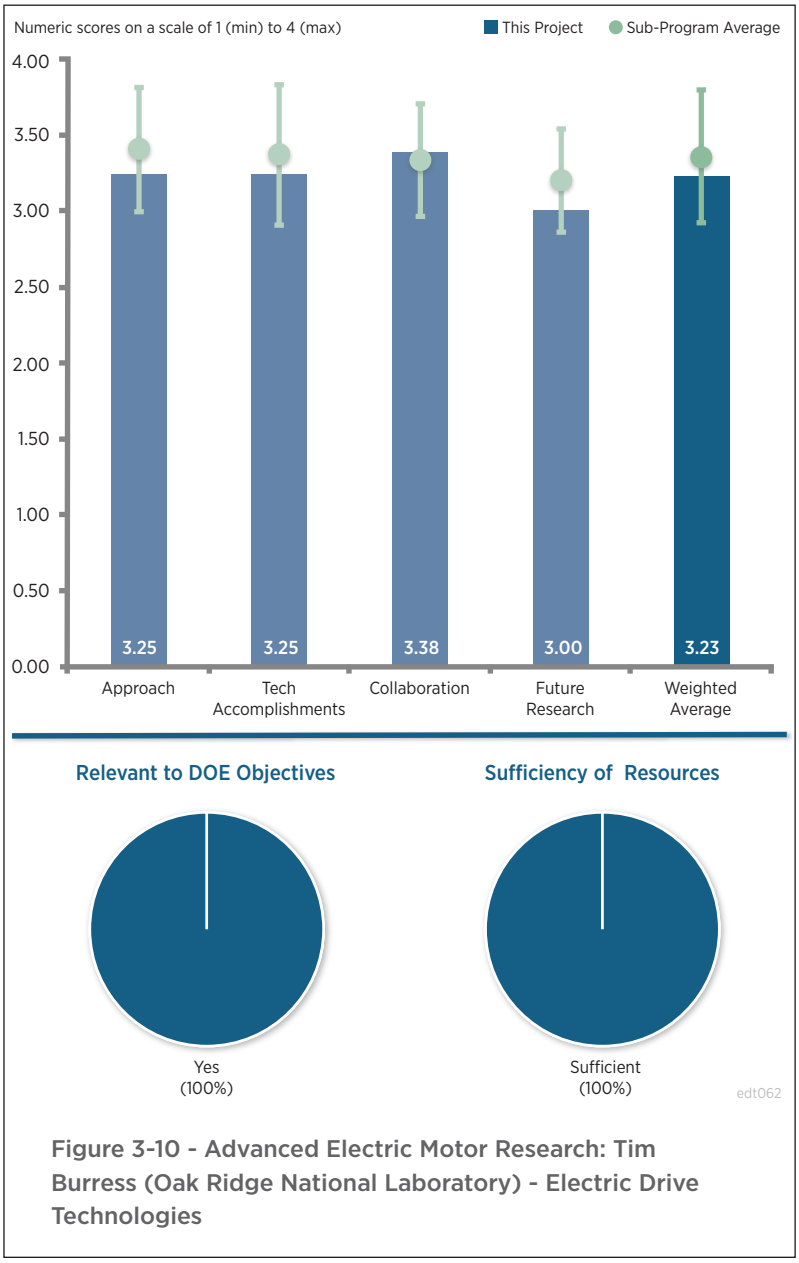

Figure 3-10 - Advanced Electric Motor Research: Tim Burress (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 1:
This reviewer recognized the comprehensive approach to the motor design and control optimization as well as the winning strategy were clearly presented. The results proved this approach very effective.

Reviewer 2:
While the approach is reasonable, this reviewer recommended reviewing the progress made so far and trying to streamline and focus the strategy towards one or two key threads with the highest potential of making impact. The current scope looks like a collection of smaller projects that all have merit, but maybe limited synergy. This person recognized at least two distinct threads; development of advanced electrical steel and a novel motor topology. However, these activities could be on very different timelines. It can take 5-10 years to develop a new material so it is hard to imagine these impacting the motors being developed within this project.

Reviewer 3:
This reviewer confirmed the project has identified the key barriers impeding progress to the final goal The parallel efforts of machine design and modeling, materials characterizations, and motor build and test are all appropriate ways to accelerate progress relative to a sequential task timeline. The tasks seem feasible for the amount of resources provided. The project seems well integrated with the efforts at NREL. This person expressed it was unclear, at least from this presentation, how much value the project is receiving from the interactions with UQM Technologies, Inc., Ames, and the University of Wisconsin.

Reviewer 4:
The reviewer confirmed heavy RE-free developments are presented in many academic research papers latel .

The success of these type of developments would depend on the specific motor design technology and successful material development. This person acknowledged that any success, however, would have significant impact for automotive application. Successful completion of this project would be quite useful; however, the project lacks clear definition

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

Reviewer 1:

This reviewer concluded the combination of modeling, materials research, and motor design and testing delivered great practical results. The optimization of the ferrite motor topology and motor performance and efficiency are the major project accomplishments.

Reviewer 2:

This reviewer characterized the project as making excellent progress in developing an alternate NRE magnet-based ferrite motor design. Fundamental work is being performed on the modeling of high Si content, soft magnetic materials with the goal of improving manufacturability.

This person declared the ab-initio and micromagnetic modeling of the magnetic domain distribution in a soft magnetic material as groundbreaking, representing the state of the art in computational materials science. This part of the project should be emphasized and focused more on modeling real-life microstructures and textures observed in rolled Si steel sheet. Further, the domain wall dynamics should be placed on a more solid theoretical foundation. This may involve broadening the collaborations to groups that have experience in micromagnetic modeling of simpler thin film systems such as magnetic recording media

The reviewer confirmed the projected performance of the ferrite motor design with distributed windings seems quite promising as compared to that in the 2010 Toyota Prius. However, it was noted that the ferrite motor performance was estimated at a magnet temperature of 100°C. Ferrite magnets are unique in that their coercivity decreases with decreasing temperature, a behavior opposite to all other commercially available permanent magnets. This person indicated it was not clear if the project had accounted for the risk of demagnetizing the magnets at the initial startup transient at room temperature, before the magnets have a chance to equilibrate at their operating temperature.

Reviewer 3:

The reviewer mentioned the team appears to have developed a novel motor architecture that can make NRE motors competitive with current RE- based motors. This is exciting; however, details of the innovation were not shared at the review so this person was not able to assess technical accomplishment. This reviewer cautioned the potential for more accurate motor models significantly impacting cost and specific power of motors was not cle .

Reviewer 4:

This reviewer stated a detailed first principle material model is presented that can predict B-H curves of non oriented electrical steel. The automotive industry works directly with the material manufacturer and relies on their expertise on high performing material development. This person noted spoke-type ferrite designs have been developed both with DOE funding as well as in the academic projects. These types of designs can provide some flux concertation but still falls short of conventional heavy RE-based designs. The reviewer judged that such construction would introduce many other mechanical issues so adoption of such designs for automotive productions is not very likely.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer applauded that the four partners' collaboration with well-defined role has been perfectly coordinated

Reviewer 2:

This reviewer said the team appears to be collaborating well with other teams in the industry and in academia. It

will be good to see how the team is incorporating lessons learned from other DOE funded efforts, such as the GE and UQM motor projects on integrated permanent magnet (IPM)/spoke rotor designs.

Reviewer 3:

This reviewer observed the collaboration with NREL appears to be tightly integrated with the efforts presented in this presentation. It was unclear from this presentation the degree to which collaboration is proceeding with Ames, UQM Technologies, Inc. and the University of Wisconsin. This person noted according to Slide 24, UQM Technologies, Inc., was to contribute injection molded potting compounds, but it was not clear where or when this occurred. Also, it was not clear to what degree the University of Wisconsin was involved in the motor design efforts.

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

Reviewer 1:

This reviewer cautioned that the future work plan is quite clear but the plan is lacking specificit .

Reviewer 2:

The reviewer suggested the stated timeline of completing the ferrite prototype by the end of September seems aggressive unless substantial portions of the hardware are already built. This person said it was also somewhat unclear how the various modeling results were going to be integrated into the advanced finite element analysis (FEA) modeling method, or how much component analysis remained to be done before that integration could take place. The reviewer wondered how are the domain wall dynamics that are being calculated in the micromagnetic modeling task being integrated into the advanced FEA modeling method and what software package is being used for the advanced FEA modeling method.

Reviewer 3:

This reviewer warned the objective and definition of this project is very general and broad. Model development with manufacturing issues such as stress, stamping damage, etc., could be useful. This person observed the project does not present any specific modeling methods that are practical and can be adopted by automotive industr .

Reviewer 4:

The reviewer said that the team should consider performing a risk assessment on proposed technologies and focus the demonstration activities on specific experiments to retire key risks, which may or may not include a full blown motor demonstration.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:

This reviewer acknowledged the project does support the DOE objectives by focusing on several promising motor technologies.

Reviewer 2:

The reviewers suggested a NRE motor that is competitive with RE-based machines will impact cost of EV/HEV's and help with DOE's objective of petroleum displacement.

Reviewer 3:

The reviewer emphasized the advanced motor designs and the soft magnetic material modeling efforts will provide considerable support to the DOE objectives of petroleum displacement. More efficient electric motor designs will reduce gallons of gasoline equivalent through direct substitution as well as increasing the marketability of electric machines. This person reinforced that improvements in the modeling and manufacturing of soft magnetic materials will have broad impact in the transportation sector beyond electric vehicles into any market segment seeing penetration of electric drive technology. This includes rail, off-highway vehicles (i.e., mining vehicles), marine, and electric aircraft propulsion.

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

Reviewer 1:

This reviewer declared the resources seem sufficient to complete the proposed tasks; howeve , the budget and timeline are only specified for F 2016, while the proposed future work has tasks listed for FY 2017.

Reviewer 2:

This reviewer stated the resources seemed to be sufficient although nothing was specifically stated in relation t that.

Performance and Reliability of Bonded Interfaces for High-Temperature Packaging: Doug DeVoto (National Renewable Energy Laboratory) - edt063

Presenter
Sreekant Narumanchi, National Renewable Energy Laboratory

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

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

Reviewer 1:
The reviewer considered the project to be well addressed with regards to the technical barriers.

Reviewer 2:
The reviewer described the approach as basic research on crack formation modeling and reliability of sintered Ag contacts.

Reviewer 3:
This reviewer expressed the approach of systematic characterization is for the most part good although higher temperature results should be captured. One large weakness is the strategy describes a lack of information at 200°C, but the testing only shows thermal cycling going to 175°C (Slide 6). If the goal is 200°C, the test should cover that range.

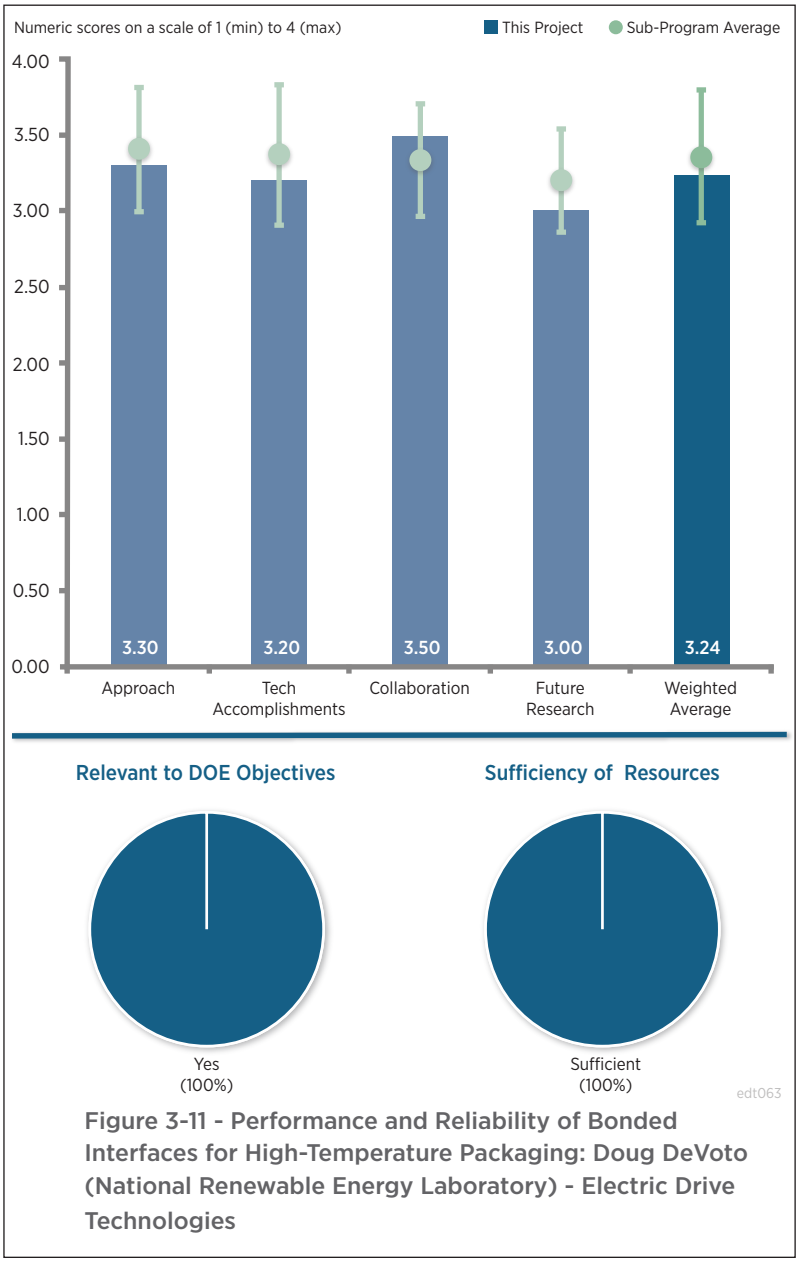

Figure 3-11 - Performance and Reliability of Bonded Interfaces for High-Temperature Packaging: Doug DeVoto (National Renewable Energy Laboratory) - Electric Drive Technologies

Reviewer 4:
This reviewer stated the reliability of bonded interfaces is key in determining the performance of the power module and the project is addressing this important topic. Reliability modeling and testing are inherently challenging tasks and the team has laid out a very systematic approach in evaluating the performance of Ag sinter based joints. The reviewer requested the team address the following comments. First, modeling the silver material in ANSYS is key to developing a useful model that users can utilize to evaluate the reliability of their designs. Typical Anand viscoplastic models may not be sufficient in accurately representing the failure mode of sintered Ag joints. The reviewer requested that the team evaluate if Anand's model is sufficient for the conditions being investigated and if not to refer to literature to determine other models that are more relevant. Second, the nature of the sintered Ag joint depends on a large number of process parameters, and the reviewer requested that the team see if porosity of

the joint is sufficient to represent these. This would greatly simplify the modeling approach and evaluation of test results.

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

Reviewer 1:
The reviewer declared this is important research that can inform the electronic packaging industry on sintered Ag.

Reviewer 2:
The reviewer pointed out the team has made excellent progress so far and has quite a few challenging tasks ahead of them. Results from this effort will clearly help in meeting DOE power electronic goals in the EDT area.

Reviewer 3:
The reviewer considered the project to be progressing well.

Reviewer 4:
This reviewer said that it is very important to understand the bonded interface crack propagation modes for high-temperature packaging. Using ANSYS to model the crack propagation may be extremely challenging. This person suggested the team think about how to verify the accuracy of the modeling work, i.e., how to compare the simulations and tests.

Reviewer 5:
This reviewer acknowledged the methods are good but do not appear to be covering the characterization at the 200°C goal. The 175°C data point is also useful, but does not reach the 200°C or greater goals. The project seems a little behind with the extra data point.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer reported there was very good collaboration between ORNL and NREL on this effort.

Reviewer 2:
The reviewer expressed that the ORNL and NREL researchers had established a very good collaboration.

Reviewer 3:
This reviewer considered that perhaps this project does not require a high degree of collaboration with other institutions.

Reviewer 4:
This reviewer stipulated that this is low level research, so it does not necessarily warrant a large collaboration team. It may be helpful if there were some sort of industry involvement, even if it were just as advisors on manufacturing techniques currently being used, or for feedback on new techniques.

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

Reviewer 1:
The reviewer stated the future work to be well defined, but it seemed the time was not sufficien

Reviewer 2:
The reviewer confirmed the continued testing is good, but should cover the full temperature (200°C) stated as the project goal instead of stopping at 175°C.

Reviewer 3:
The reviewer concluded the project has made good progress and has some challenging tasks ahead. Modeling crack propagation in simulation is interesting. This person suggested that the team check if this is necessary or if it would be sufficient to estimate strength reduction

Reviewer 4:
This reviewer said that using ANSYS to measure the crack propagation may be extremely challenging. The team may want to evaluate the computational requirement and time to conduct this simulation.

Reviewer 5:
This reviewer warned the milestones are not very strong although this work appears to show good results.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer pointed out the project addresses reliability of bonded interfaces, which is a key failure mechanism in power converters. Power converters are a key component of electric hybrid technologies and hence this project is clearly in line with DOE goals.

Reviewer 2:
The reviewer confirmed the work of characterizing the sintered-Ag would be helpful and critical

Reviewer 3:
The reviewer noted that the performance and reliability of higher temperature electronics is not well documented. In order for DOE to meet its power density goals, and for the electronics to be installed in areas like the engine compartment, higher temperatures need to be tolerated by the electronics. This person said this research is enabling information that will help electronic designers know the electronics' limitations and help with design choices/ methods for building the high-temperature electronics that will meet the DOE goals.

Reviewer 4:
The reviewer ascertained it is very important to understand the bonded interfaces failure mechanism as DOE is targeting to further increase the power density of the vehicle traction inverters.

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

Reviewer 1:
The reviewer noted the resources seem to be sufficient to accomplish the goals

Reviewer 2:
The reviewer declared the resources to be sufficient

Electric Motor Thermal Management R&D: Kevin Bennion (National Renewable Energy Laboratory) - edt064

Presenter
Kevin Bennion, 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 reported that the project is well positioned to contribute valuable information on the heat transfer performance of motor end windings. The experimental and data collection efforts are well designed and appropriate for collecting the required data. This person noted that the collaborations with the partners, particularly ORNL, appear to have led to cross-cutting impact.

Reviewer 2:
The reviewer indicated that the approach is great, with both good fundamental and rigorous experimental work. This person suggested that perhaps there is opportunity to broaden the impact of the project. The team may want to consider increasing the collaboration with one of the motor design efforts to integrate novel cooling schemes derived from the new understanding being obtained from bench tests. The reviewer said it will also be good to see the connection to complete machine models described in more detail. This person questioned if standardized salable models be can be generated and shared broadly.

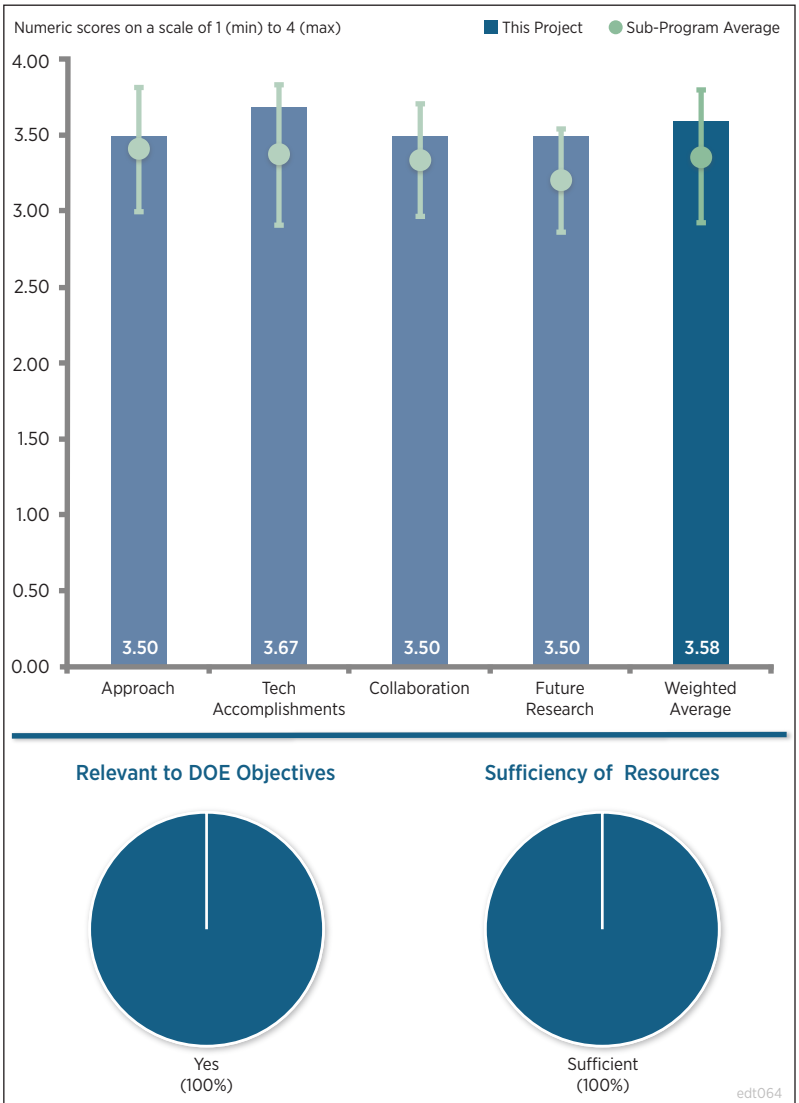

Figure 3-12 - Electric Motor Thermal Management R&D: Kevin Bennion (National Renewable Energy Laboratory) - Electric Drive Technologies

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

Reviewer 1:
The reviewer observed, though this topic sounds simple and fundamental, there is no literature on the cooling effect of direct spraying of transmission fluids on surfaces representative of electrical machines, and certainly no publicly available empirical data that motor designers can use to optimize their machines. This person suggested that this project fills that gap

Reviewer 2:
The reviewer indicated that the jet impingement test rig represents a simple, effective method for measuring the heat transfer coefficients in realistic winding configurations. It is well suited for measuring the direction-dependen thermal conductivity of laminate stacks as well as the thermal contact resistances. The reviewer noted that the comparison between fan and orifice jets covers the range of impingement methods used in practical motor designs. The thermal contact resistance on passive materials also provides valuable data for motor designers, the reviewer stated.

Reviewer 3:
The reviewer mentioned that the measurement of the heat transfer coefficient with automatic transmission fluid (TF) flow as a function of flow rate could be quite useful. In addition, proposing several orifice jets a subsequent estimation of the thermal coefficient and the measurement of heat transfer coefficient from the en winding could be very useful as well. The reviewer concluded that these data should be useful for automotive thermal estimation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer reported that it appears this team is working closely with other motor focused projects and helping with their modeling efforts. The interaction will benefit both sides, the reviewer stated

Reviewer 2:
The reviewer said that the collaboration with ORNL was well documented, but it was unclear if there were any collaboration with Ames directly relating towards the goals of this project.

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

Reviewer 1:
The reviewer indicated that the project team has a clear, focused plan for performing representative tests to better understand oil spray cooling. This person suggested the project team should consider being more ambitious in the test campaign and partner with others to investigate novel machine level cooling schemes that can impact motors being developed currently.

Reviewer 2:
The reviewer stated that the proposed future research should complete the remaining goals and objectives of the project.

Reviewer 3:
The reviewer remarked that the project concentrates on stranded design. This person suggested that it would be interesting to know how a bar wound motor would perform. Estimating these parameters for bar wound motors would be quite useful, the reviewer said.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer commented that this work indirectly supports the DOE objectives of petroleum displacement by providing much needed experimental data on heat transfer coefficients and thermal resistances to electric machine designers. This person stated that this will help the industry reach the 2022 system performance targets, thus making the domestic EV industry more competitive.

Reviewer 2:
The reviewer acknowledged that thermal constraints are clearly a key barrier to improved power density and cost of electric machines and drives. This person suggested that if efficiency considerations allow it, better

understanding of oil impingement cooling and other advanced cooking schemes can enable more cost effective electric traction systems.

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

Reviewer 1:

The reviewer indicated that the resources and timeline as indicated are sufficient for the team to complete their stated milestones.

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

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 considered the project to be well designed and feasible. In addition, the technical barriers have been well addressed.

Reviewer 2:
The reviewer explained that electric vehicles require battery chargers to fill the tank and it needs to be efficien due to the length of time that it will be charging, which is based on battery size and charger capability. A typical limit for a normal household without having to add special wiring or plugs is 6.6 kW. With the EV market spreading to areas with less than perfect weather, the addition of a bi-directional charger allowing for the EV battery to be used for providing power to the home is a good addition to the vehicle. This person reported that Delta has chosen to use a high frequency switching design based on GaN devices, which allow a switching frequency much greater than the typical 50 kHz found in Si-based chargers. The higher switching frequency allows the passive components such as capacitors and inductors to be significantly smaller thus allowing for a more compact design as well as an efficient design. The reviewer reported that the approach of building a Si-based charger to verify the concept and allow controls to be developed while the GaN devices were being improved allowed the team to concentrate on technical issues related to the new hardware rather than trying to determine if the problem had hardware, software, or control as the source. This person also pointed out that another good approach was carrying a second architecture designed by their partner, Virginia Tech, which had the same operational goals but different implementation which allowed them to select the better design.

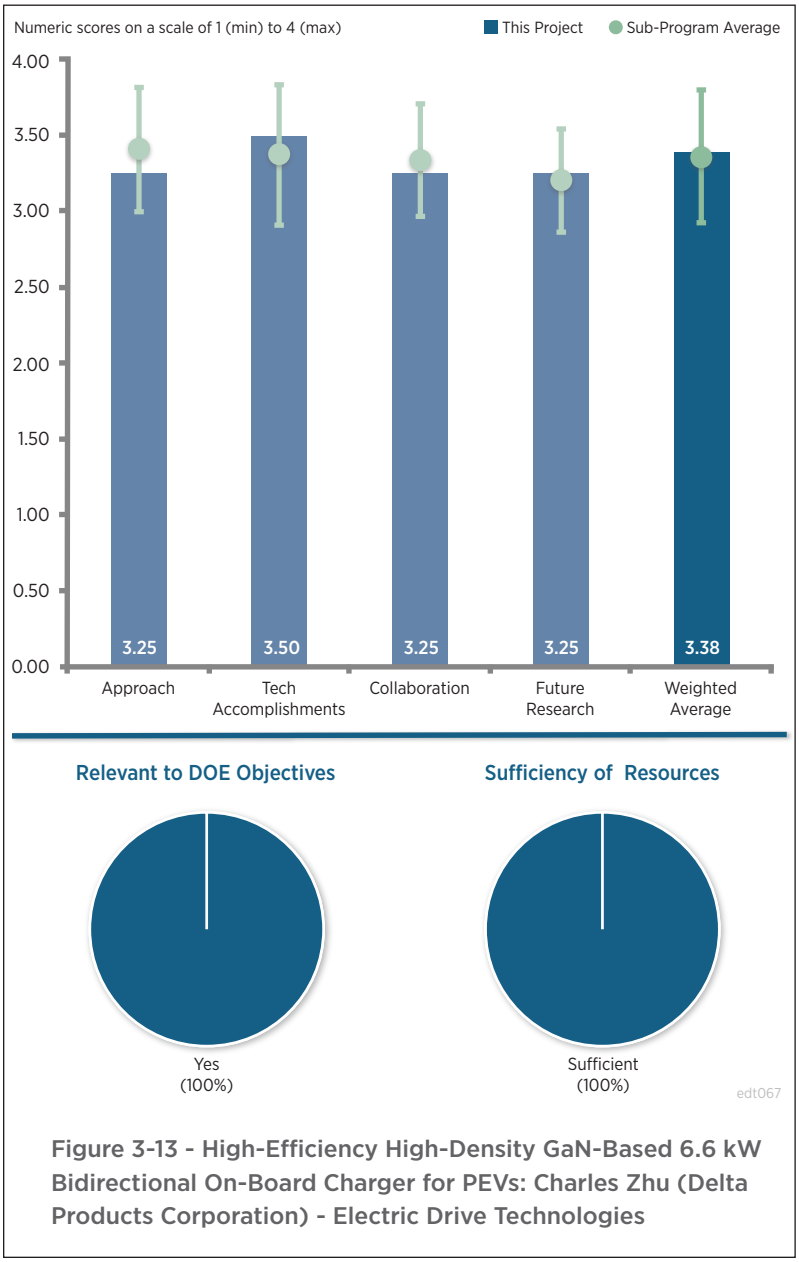

Figure 3-13 - High-Efficiency High-Density GaN-Based 6.6 kW Bidirectional On-Board Charger for PEVs: Charles Zhu (Delta Products Corporation) - Electric Drive Technologies

Reviewer 3:
The reviewer remarked that reducing the number of switching devices will reduce cost of OBC and simplify packaging of OBC converter systems. In addition, increased switching frequency will reduce magnetics size and

cost of magnetics used in OBC. The reviewer recommended that the PI should explore a possibility that the vehicle identifies if there is one 3.3 k OBC or there are two 3.3 kW OBC in parallel, and then configure the control system so that interleaving could be used to reduce EMI, EMC, and filtering capacitor requirements

Reviewer 4:

The reviewer noted that the approach consists of two basic statements, which are to reduce the number of switching devices and increase the switching frequency. This person pointed out that the statements are not quite well coordinated with the project objectives and goals.

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

Reviewer 1:

The reviewer stated that the target efficiency achievement and excellent dynamic load responses are two major accomplishments. This person commented that the dependency of the system topology upon specifics of the GaN switches and associated challenges in driving and cooling them has not been addressed sufficientl .

Reviewer 2:

The reviewer indicated that the design, build, and testing of charger versions using three iterations of GaN switches is impressive. The performance and efficiency of the device as both a cha ger and an inverter is quite good. The reviewer prefers the two parallel 3.3 kW power stages as it provides options for use such as running a single stage if connected to a 120 V alternating current, 16 ampere service and still operate at a reasonable efficiency point. This approach can also be used to provide fault tolerance if desired. Performance of both the mainstream and back up charger are both very good with the backup charger being higher risk due to the power levels that the circuit card needs to handle with the planar magnetic approach which does save space and volume. The reviewer remarked that when the cost of GaN devices drops to competitive levels and the Virginia Tech University Center for Power Electronics Systems (CPES) in-board inductor method has been made into a product, these designs will be very competitive in the EV charger market place.

Reviewer 3:

The reviewer reported that three iterations of GaN MOS field-e fect transistor (MOSFET) were evacuated and a GaN device supplier states that reliability of iterations of GaN MOSFET has improved reliability offered by iteration I and II GaN MOSFETs. The topology of concept design was selected. The prototype of 3.3 kW GaN OBC was developed and tested for power-factor and efficienc . The reviewer further explained that the efficiency of 3.3 kW GaN OBC is also measured at variable voltage across the battery and it is identified that 350 V could be the preferred voltage for the on-board battery. Additionally, the reviewer noted the following: concept topology of 6.6 kW OBC is proposed; project report includes a picture of the sample 6.6 kW OBC; and the project report includes a variety of test results.

Reviewer 4:

The reviewer considered the progress to be moderate. This person would like to see the justifications for developing a 6.6 kW module by paralleling two 3.3 kW modules. The reviewer questioned whether it would be feasible to parallel switch modules or do multiphase. Specific to the DC/DC and PFC stages, this reviewer asked whether the same challenges would be faced when scaling from 3.3 kW to 6.6 kW. The reviewer also suggested a system architecture optimization procedure.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer stated that the role of each partner was well defined and the coordination of e forts appeared to be effective.

Reviewer 2:

The reviewer indicated that the PI has clear plan to work with academia (Virginia Tech), key part supplier (Transform), and end-user industry (Fiat Chrysler Automobiles [FCA]).

Reviewer 3:
The reviewer did not see a clear contribution from FCA.

Reviewer 4:
The reviewer said that the team collaboration appears to be functioning well at least with Delta and Virginia Tech University CPES. This person observed that the vehicle integration task will need to rely on the FCA connection and has no reason to believe that it will not work well.

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 reported that the future planned tasks are logical and reasonable and should lead to a successful completion of this project. This person questioned what the control interface between the vehicle and the grid will be because this was not mentioned.

Reviewer 2:
The reviewer noted that the emphasis on the vehicle test and the creation of the commercialization plan are very important.

Reviewer 3:
The reviewer commented that deployment and testing of OBC in the vehicle is identified as future research

Reviewer 4:
The reviewer remarked that the future work needs to be better defined

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer stated that using the vehicle charger as the emergency power to your house is the very important feature benefit

Reviewer 2:
The reviewer acknowledged that WBG devices-based OBC research work underway at Delta falls within the objective of DOE due to higher efficiency possible with the GaN based OBC system

Reviewer 3:
The reviewer considered this project supported the overall DOE objectives well.

Reviewer 4:
The reviewer explained that as EVs become a larger percentage of the vehicle usage in the world market, the amount of energy required to charge them will require more efficient cha gers. The addition of bi-directionality will not only be an attractive option but may soon be seen as an imperative especially in areas prone to loss of power and as the smart grid becomes more common place which can take advantage of this capability. The reviewer pointed out that it might even pay for the additional cost of the circuitry.

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 were definitely sufficient This person observed that the amount of work that has been done considering the relatively low budget was quite impressive.

Reviewer 2:
The reviewer considered the resources to be sufficient

Reviewer 3:
The reviewer mentioned that the progress to date indicates that at the design level the resources are adequate. This person indicated that the device development may have under-estimated the number of turns to produce the desired level of performance, which is understandable as it is a complicated task.

Gate Driver Optimization for WBG Applications: Nance Ericson (Oak Ridge National Laboratory) - edt068

Presenter
Nance Ericson, 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 considered this project to be very helpful to the research and development of the WBG applications in the auto industry.

Reviewer 2:
The reviewer remarked that the approach is sound benchmarking against existing chips, followed by iterating and improving them with advanced methods and controls.

Reviewer 3:
The reviewer explained that the project focuses on optimizing the gate drive for WBG devices with an aim to control the instantaneous rates of change of voltage (dv/dt), and current (di/dt). This is a fairly challenging task but definitely has benefit to improve system level performance (decreased EMI and motor breakdown). Howev , there are quite a few challenges that the team is asked to respond to. First, typically in a module or a package, the manufacturers tend to reduce common source inductance to improve switching speed. This would negatively impact the measurement required for the proposed scheme. The reviewer requested that the team derive what the minimum common source inductance is required for this scheme to work. The second challenge is that in a module, multiple dies are placed in parallel and invariably these have slightly different parameters (transconductance, threshold voltage, etc.). The reviewer questioned how this can be addressed in the proposed scheme.

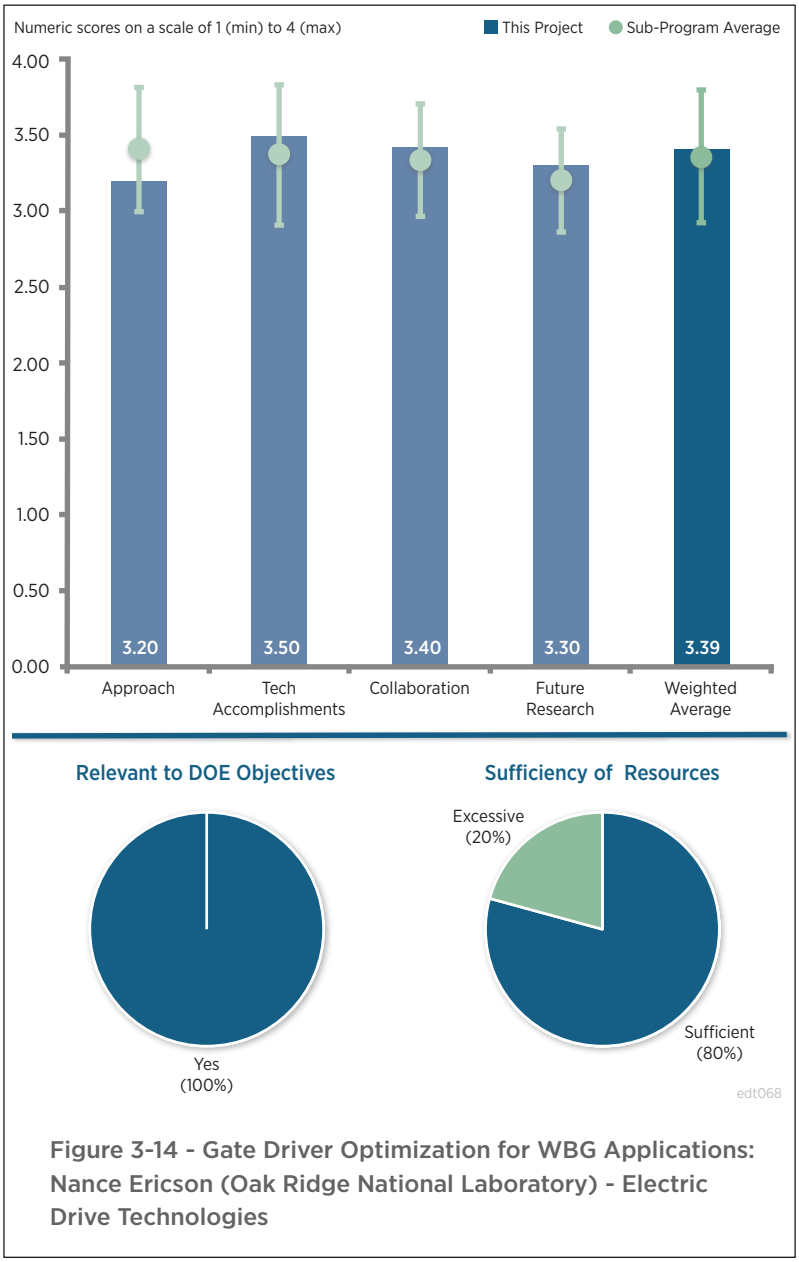

Figure 3-14 - Gate Driver Optimization for WBG Applications: Nance Ericson (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 4:
The reviewer noted that previous attempts by commercial integrated circuit (IC) houses to produce analog feedback-based gate drivers for (relatively slower) Si MOSFETs have been failures because of the very high bandwidths needed and the accompanying problems with layout, grounding, etc. The reviewer is very skeptical that this project will succeed. This person commented that the 4 kilowatt per liter (kW/L) stated power density target is out of date.

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

Reviewer 1:
The reviewer pointed out that optimizing the gate drive performance is very important to the WBG device based inverter performance and reliability and helps mitigate the voltage stress on the motor and bearing current. This person stated that there has been excellent progress made to simulate the performance of the proposed gate drive circuits. The reviewer acknowledged that the team has completed the hardware design and is looking forward to seeing comprehensive test results next year.

Reviewer 2:
The reviewer mentioned that the project is tracking well and appears to be on track to meet its goals. Simulations and baseline testing were done and the design improvements are in progress, the reviewer reported.

Reviewer 3:
The reviewer observed that the team has shown very good progress so far. Modeling and simulation work look thorough and experimental evaluation has a very good likelihood to be successful.

Reviewer 4:
The reviewer stated that simulation is fine, but the experiment will be a key to proving feasibility of this approach. This person warned that it appears that there is very little time left to meet the very difficult experimental milestones and go/no-go checkpoint. The plateau voltage control scheme appears to be novel, remarked the reviewer.

Reviewer 5:
The reviewer would like to know the measures to evaluate the stability of the integrated gate drive. This person also questioned if the specific ta get is efficiency or frequenc .

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer acknowledged that there is collaboration between ORNL and the University of Tennessee, Knoxville (UTK) researchers. This person suggested that this project would benefit from direction by IC producers with interest in the area of WBG gate drivers.

Reviewer 2:
The reviewer commented that the project has a good team with a manufacturing partner, Wolfspeed, a chip manufacturer and potential transition partner, and academia (UTK) represented.

Reviewer 3:
The reviewer noted that from the presentation it looks like the team is leveraging the competence of UTK in gate drive design and chip development. Device simulation appears to be in partnership with CoolCad.

Reviewer 4:
The reviewer agreed that all the partners have contributed to 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 noted that the future work had been well defined and planned

Reviewer 2:
The reviewer pointed out that the upcoming milestones are appropriate although tight. This person is skeptical that the experimental milestones will be met.

Reviewer 3:
The reviewer commented that the future research for the gate driver is good. This person said that it is unclear how the solution will be implemented as the presentation indicated isolation is still needed. The researcher suggested that, at a minimum, whatever isolation is required should be tested and recommendations for various implementations should be included in the future research.

Reviewer 4:
The reviewer declared that the project is addressing quite a challenging task. The reviewer suggested that, in the proposed future work, the project team be asked to incorporate automatic tuning (from user) to achieve desired dv/dt and/or di/dt instead of manual tuning and device parameter variation and impact of paralleling devices on the proposed scheme.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer indicated that an optimized gate driver circuit for WBG devices is an enabling technology to help DOE meet its goals.

Reviewer 2:
The reviewer stated that WBG device performance and system benefits depend on proper gate drive design. The project addresses a key risk in utilizing these devices and hence clearly supports the overall DOE objectives, commented the reviewer.

Reviewer 3:
The reviewer considered this project to be well supportive of the overall DOE objectives.

Reviewer 4:
The reviewer observed that the reliability of the inverter and motor system using the WBG devices will improve the performance and efficiency of the future HEV/ PHEV/BE products.

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

Reviewer 1:
The reviewer commented that this topic is of high importance to the proper use of WBG devices. The project scope is quite challenging, and $200,000-$250,000 appears to be too small for addressing the proposed research and the additional concerns raised by the reviewer.

Reviewer 2:
The reviewer said that the resources appear to be sufficient to meet the goal

Reviewer 3:
The reviewer considered the resources to be sufficient

Power Electronics Thermal Management R&D: Gilbert Moreno (National Renewable Energy Laboratory) - edt069

Presenter
Kevin Bennion, 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 acknowledged that the project focuses on the thermal bottlenecks to using WBG devices in under hood applications. Simulation results show the expected temperature rise in various components and the effect of increasing under hood temperature. The reviewer concluded that this is a key topic for successful incorporation of WBG devices.

Reviewer 2:
The reviewer considered this project to be interesting, but the applications of the thermal management techniques need to be better defined

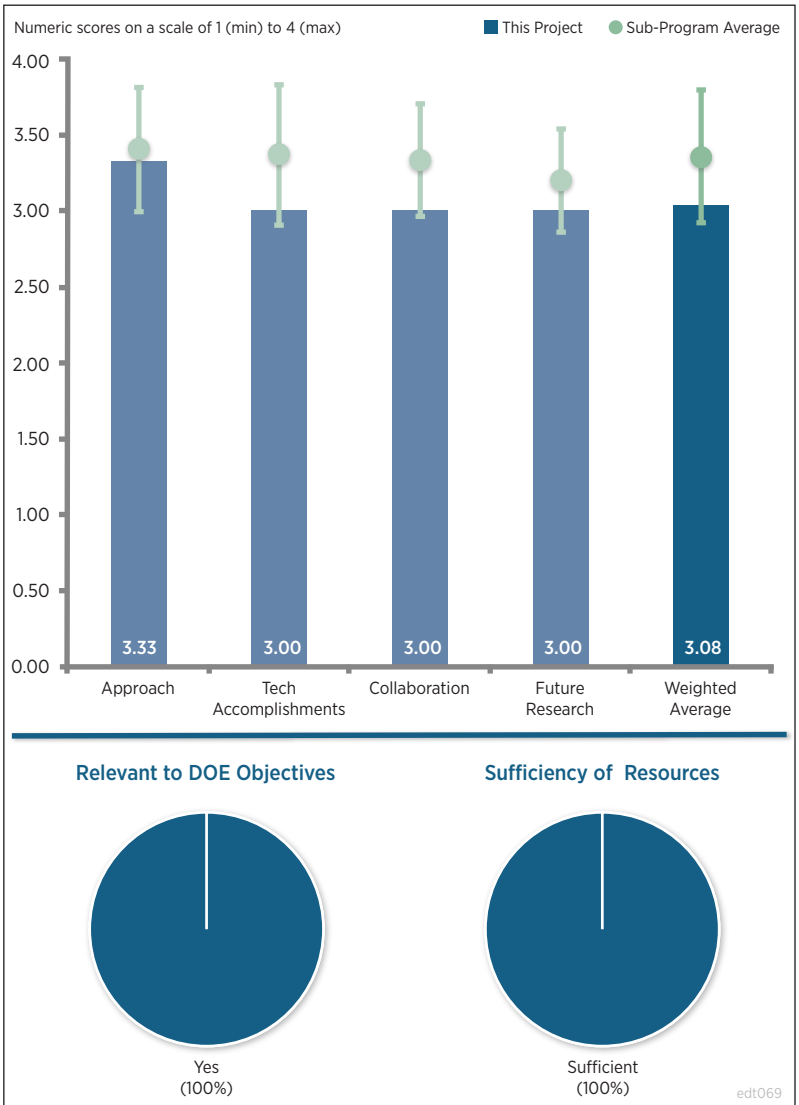

Figure 3-15 - Power Electronics Thermal Management R&D: Gilbert Moreno (National Renewable Energy Laboratory) - Electric Drive Technologieses

Reviewer 3:
The reviewer identified macro scale thermal modeling of PE systems. This person further noted that the project started with a 2012 LEAF (benchmarked by Burress), developed thermal system model, and then considered effects of modifications improvements.

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

Reviewer 1:
The reviewer reported good experimental validation and good insights. The reviewer questioned if this will be applied to a John Deere design. This person noted that the comments on 140°C capacitors are consistent with what others have observed and questioned if there is a proposed solution.

Reviewer 2:
The reviewer stated that the thermal modeling work carried out is comprehensive; however, validation of the

thermal model is limited to few components. This person requested that the team check if more experimental data are available or can be carried out to validate the model.

Reviewer 3:

The reviewer reported that the percentage of the work completed seemed to be insufficient. The reviewer would like to see a flowchart or other representation that summarizes the thermal management methodology which would be applicable for most inverter and converter designs. This person would also like to see a comparison of the issues or challenges of the thermal management techniques for Si-based and WBG devices.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer noted that the team appears to have good collaboration with other institutions.

Reviewer 2:

The reviewer commented that apparently there is collaboration with John Deere and Kyocera, but no details were given so this is difficult to judge

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

Reviewer 1:

The reviewer pointed out that the project has reached a key point where new technologies need to be evaluated for thermal management. This person observed that jet impingement techniques appear to be unsuitable for some cases but no details on the other potential solutions are presented.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:

The reviewer explained that thermal management is a key challenge for hybrid electronics and the project is well aligned with DOE objectives.

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

No comments were received in response to this question.

Thermal Performance Benchmarking: Xuhui Feng (National Renewable Energy Laboratory) - edt070

Presenter
Xuhui Feng, National Renewable Energy Laboratory

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

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

Reviewer 1:
The reviewer reported that this approach to select a vehicle, measure the desired performance attributes, create models, and validate it using the data makes sense. Based on the data and validated modeling to determine what needs to be done to improve the performance is also a logical step. This person indicated that this project will include the electric motor and transmission as well as the PE but it was not clear if the PE includes a charger and 12 V power supply for the vehicle. The reviewer thought that just the drivetrain is fine

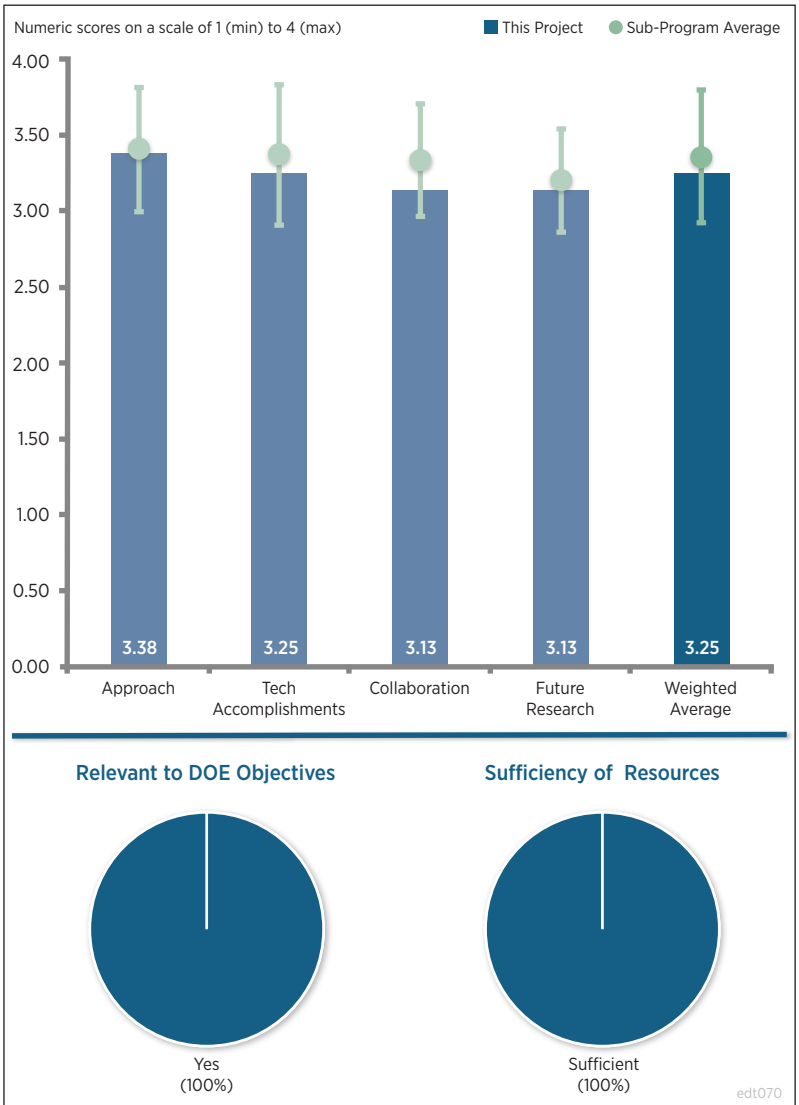

Figure 3-16 - Thermal Performance Benchmarking: Xuhui Feng (National Renewable Energy Laboratory) - Electric Drive Technologies

Reviewer 2:
The reviewer observed that this project examines state of the art thermal management systems employed in EVs and HEVs. The results can be used to guide future R&D in thermal management, which can lead to higher efficiency and reliability in the vehicles. This person indicated that the project is aligned with ORNL's benchmarking project.

Reviewer 3:
The reviewer mentioned that the Nissan LEAF and Honda Accord inverter's thermal performance have been analyzed. This person further noted that the Nissan LEAF is shown to possibly have cost and reliability advantages.

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

Reviewer 1:
The reviewer stated that the technical progress looks good. This person mentioned that thermal management

systems for the 2012 Nissan LEAF and the 2014 Honda Accord were characterized and compared to finite element models and that several areas of improvement were identified

Reviewer 2:
The reviewer reported that the information provided on the analysis and testing of the Nissan LEAF and Honda Accord provided good results for the cooling systems. The comparison charts are a good method to show the differences between the approaches. This person pointed out that the conclusions in the report were substantiated by the data indicating that the process is controlled. The reviewer noted that, as mentioned in the presentation, the test conditions do not match in vehicle conditions. This person asked if there is a plan to develop vehicle instrumentation procedures to provide an indication of what these might be. The reviewer realized that the vehicle environment is pretty harsh for instrumentation, but perhaps a few significant test points might be monitored during the routine vehicle testing being performed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated the project team is collaborating with ORNL.

Reviewer 2:
The reviewer acknowledged that this project aligns well with ORNL's benchmarking project (edt006).

Reviewer 3:
The reviewer voiced that collaboration between the laboratories appears to be working well in this case.

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

Reviewer 1:
The reviewer pointed out that the project team will focus on thermal management characterization of the 2015 BMW i3 PE, inverter, and motor.

Reviewer 2:
The reviewer commented that the future research is focused on the BMW i3, which complements the work in EDT006.

Reviewer 3:
The reviewer observed that the plan to continue to characterize the performance is reasonable, but the reviewer is not sure how the project team will characterize and improve the thermal performance on a production vehicle. This person questioned if the plan is to modify the thermal stack up, heatsink, and thermal fluid path, or just modify the models and simulate the results. The reviewer asked, if so, how the project team will validate this process.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer stipulated that this work can guide future thermal management R&D efforts and identify areas to improve efficienc , reliability, and cost.

Reviewer 2:
The reviewer remarked that the thermal system performance drives the number of switching devices required, has a significant impact on the size and mass of the PE, and to a la ge degree the amount of power that the electric machine can deliver within its cost target, which makes it relevant.

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

Reviewer 1:
The reviewer said that the project appears to have sufficient resources

Reviewer 2:
The reviewer explained that the data indicate that the resources are sufficient for the current project objectives. If on-vehicle testing and/or performing modifications to the hardware are added, then the resources may not be adequate but then that is a scope change, the reviewer noted.

Electric Motor Performance Improvement Techniques: Lixin Tang (Oak Ridge National Laboratory) - edt071

Presenter
Lixin Tang, 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 indicated that the project clearly states the technical barriers towards realizing the goals of multispeed motor control schemes with series and parallel windings. The development program as outlined appears to have made substantial progress towards comparing and contrasting the benefits and drawbacks of this method. The reviewer pointed out that the increase in focus on understanding system cost and complexity, as well the outreach to external partners such as Borg Warner, was particularly noteworthy.

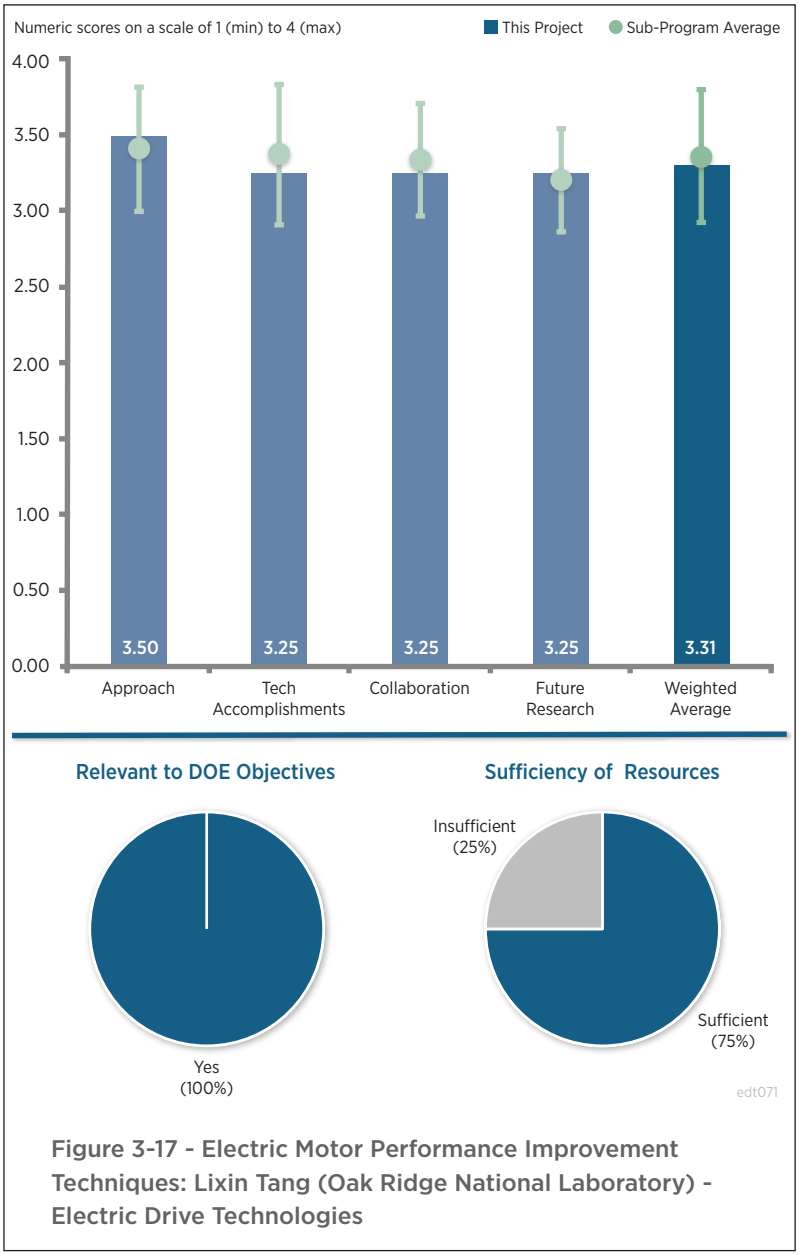

Figure 3-17 - Electric Motor Performance Improvement Techniques: Lixin Tang (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 2:
The reviewer commented that it is good to see a motor plus drive system level approach that can help reduce motor size, weight, and cost. This person said it is especially interesting because solutions that require more active switching could become more attractive given the rapid advances being made in PE.

Reviewer 3:
The reviewer mentioned that the project seeks to increase the power density and efficiency of electric drives by using reconfigurable windings in the moto . The project team is investigating several methods and the high level approach seems good. The reviewer noted that the specific approach was not presented, but that is understandable because some of the design is under patent review.

Reviewer 4:
The reviewer remarked that the use of a multi-speed range (MSR) motor is one potential approach to achieving the desired performance goals. In theory, it will work but there are still issues that need to be addressed before it is acceptable for use in a vehicle. The reviewer suggested that these include issues with torque interruptions during

range switching, added cost of the switches, and torque issues in the event of a failure. This person emphasized that before the MSR can be judged successful, it must compete not only in terms of performance but also in the cost and packaging. This has not been addressed to date.

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

Reviewer 1:
The reviewer stated that the project team has made excellent progress on understanding a key risk of the multi-speed method, namely the reconfiguration transient that occurs when switching from series to parallel mode and vice-versa. In addition, the potential reduction of permanent magnet content was noteworthy but should be verified in a tested prototype. The reviewer noted the FEA-generated efficiency maps were thoroughly developed

Reviewer 2:
The reviewer said that the simulation results look very promising with increased power density and efficiency over traditional designs.

Reviewer 3:
The reviewer observed that the project team has made good progress by optimizing the design and quantifying system level value through analysis. The real challenges may be with reducing this to practice and understanding challenges that show up when an actual motor is integrated with the drive at scale. This person questioned what happens to transients as inductances scale-up, how stable are the controls as the motor operates continuously at a speed close to the transition, and are there any reliability considerations with a large number of repeated switching.

The reviewer mentioned that it would be good to understand why this promising approach has not been pursued seriously even though it has been proposed in the past (e.g., Panchien, L. I. N. "Adaptive winding system and control method for electric machines." U.S. Patent No. 7,977,842).

Reviewer 4:
The reviewer noted that the simulated results indicate that this approach has potential and have started to address some of the concerns, such as the torque interruptions. This person questioned if the cost comparisons on Slide 8 include the cost of the gate drive or just the switches. In addition, the reviewer wanted to know what the implications are in terms of the inverter packaging by adding additional switches and gate drives as well as the added complexity of routing the power to these switches. Furthermore, the reviewer was interested to find out if the project team can provide an efficiency map of the inverter for the two operating modes. Lastl , this person was interested in finding out what the impact is to the drive unit with the increase in stator outer radius increase to 141 mm from 100 mm and if this will cause issues with vehicle mounting.

The reviewer pointed out that, at this point in the project, the progress has been limited to simulations only, which indicate that the approach has merit along with issues that need to be addressed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed that at this early stage the team is probably doing as well as they can in collaborating with others. As the technology readiness levels (TRL) increase, closer collaborations with industry may be required to understand and address practical issues with implementing this architecture in a product.

Reviewer 2:
The reviewer stated that the team is collaborating with Borg Warner on the design of their motor hairpin windings and cost evaluation of the system.

Reviewer 3:
The reviewer indicated that the team appears to be working well together performing the simulations. The proof will be in the building of a prototype system.

Reviewer 4:
The reviewer reported that the project team responded well to a previous reviewer's suggestion to engage an outside collaborator to understand the system cost impact of multi-speed control. This person suggested that the project team should leverage this collaboration to the maximum extent possible to understand the cost increases due to additional parts and motor complexity.

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 indicated that future research is in line with the original plan and what is needed to provide the required data to determine if this is indeed a valid approach to meeting DOE's 2022 goals. This person suggested that the additional simulations should focus on identifying the source of the circulating current as well as control methods for minimizing torque transients while switching modes. The challenges identified in the presentation are still valid.

Reviewer 2:
The reviewer acknowledged that the team will optimize, build, and test the benchtop prototype in FY 2016 and work on the final design in F 2017.

Reviewer 3:
The reviewer suggested that a failure mode and effects analysis (FMEA) and risk assessment could help guide future work by the team. It may make sense to consider demonstration of a motor and drive at close to full rating to understand scale-up issues. Also, it would be interesting to see how similar approaches would impact induction machines, maybe by including pole changing techniques.

Reviewer 4:
The reviewer commented that building the benchtop and final prototype is an appropriate method to verify the model predictions. However, the available budget may make this challenging unless a substantial amount of the hardware is already built.

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer stated yes, this project supports the petroleum displacement objective by investigating the use of a potentially more efficient motor design

Reviewer 2:
The reviewer indicated that the goals of this project include increasing the efficiency and power density of the electric drive system, both of which decrease energy use in the vehicle.

Reviewer 3:
The reviewer pointed out that with the design space opened up by the reconfigurable windings, more optimal machines that meet torque speed requirements at lower cost and lighter weight could be designed, which can in turn lead to improved viability of EV/HEVs.

Reviewer 4:
The reviewer commented that this project is one method to increase the efficiency at low torque and speed levels that needs to be investigated to determine if it is viable.

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

Reviewer 1:
The reviewer explained that, if the team decides to adopt the above recommendation for demonstration of a motor and drive at scale, significantly more resources would be required

Reviewer 2:
The reviewer agreed that the budget for the final build and test seems appropriate if existing hardware can be effectively leveraged.

Reviewer 3:
The reviewer noted that the resources for this project appear to be sufficient

Reviewer 4:
The reviewer mentioned that, based on the simulations, resources appear to be sufficient to date. This person further described the resources as sufficient if the concerns are addressed in a timely manne .

88 Kilowatt Automotive Inverter with New 900 Volt Silicon Carbide MOSFET Technology: Jeffrey Casady (Cree) - edt073

Presenter
Jeffrey Casady, Cree

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 declared that the emphasis on achieving the lowest R_{DSON} over operating temperature range and the reduction of the power losses in comparison with insulated-gate bipolar transistors (IGBT) and high-temperature operation address the critical barriers perfectly.

Reviewer 2:
The reviewer considered this to be a well-designed and structured project.

Reviewer 3:
The reviewer reported that this project is concentrating on the development and commercialization of an automotive-qualified, high-power SiC MOSFE with plans to demonstrate it in an inverter. The approach shown is logical and realistic in timing assuming that the modifications from the previous version are successful which is reasonable since it is an improvement to a known chip. This person suggested that the process is by no means a simple one but appears to be well understood by the project team. The reviewer indicated that the project team is improving the basic building block of the power module. The module appears to have been designed on a different project but with the new device in mind.

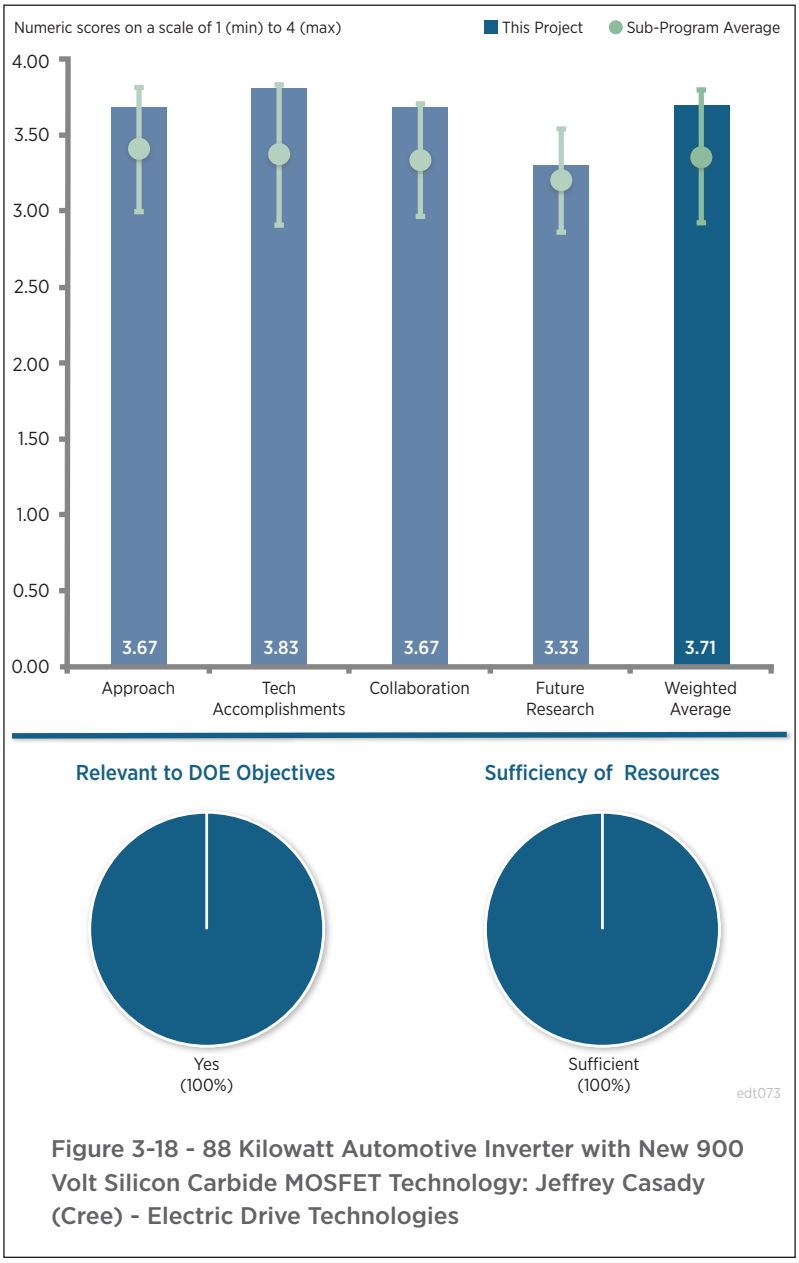

Figure 3-18 - 88 Kilowatt Automotive Inverter with New 900 Volt Silicon Carbide MOSFET Technology: Jeffrey Casady (Cree) - Electric Drive Technologies

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

Reviewer 1:
The reviewer acknowledged that the innovative 900V module design and the conduction and switching losses reduction (67% total losses reduction) in comparison with the state-of-the-art automotive Infineon IGB module are the major technical accomplishments of the project.

Reviewer 2:
The reviewer stated that the test data presented indicates that the project team has been successful in building this improved device. This person noted that the modeling of vehicle performance using these devices shows a significant increase in efficiency at the vehicle level, which correlates with the data shown in th APEI inverter project efficiency maps. The project team has manufactured a significant number of wafers and dies for use during the qualification and the results to date are very good. The reviewer questioned if the TO247-4 maintains its performance advantage over the TO247-3 package over the full temperature range. The reviewer suggested that the real test will be what the actual inverter testing show as the performance increases and wondered if it will match the simulation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said collaboration with nine automotive OEMs demonstrates the undisputable practical value of the project's results.

Reviewer 2:
The reviewer explained the team members are appropriate for this project and seem to be working well together. This person is not sure how the creation of Wolfspeed will impact this project but the results to date indicate the team is working well together.

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

Reviewer 1:
The reviewer mentioned that the AEC-Q101 qualification plan at the chip level and the three-phase inverter demonstration is the great future plan and the path to the commercialization. The project has a very high real application potential in terms of the future production, said the reviewer.

Reviewer 2:
This person remarked that the proposed future work is the next step in readying the device for commercial use, which includes finishing the qualification and demonstrating the reliability of the devices and modules The schedule for this was not shown nor was any significant concern mentioned during the presentation

Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer stated that the DOE objectives were directly addressed by the project scope.

Reviewer 2:
The reviewer indicated that the switching device is the main determining factor in the performance of an EV and any improvement in that device is relevant.

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

Reviewer 1:
The reviewer reported that a lot was accomplished with the given resources and acknowledged it was really impressive.

Reviewer 2:

The reviewer mentioned that the number of devices manufactured and tested indicate that the resources were sufficient for this project. This person pointed out that the test results indicate that the resources used in the design of the device were very capable in doing their job.

Acronyms and Abbreviations

3D	Three-dimensional
A	Ampere
AC	Alternating current
AEC	Automotive Electronics Council
Ag	Silver
Al	Aluminum
AlNiCo	Aluminum-nickel-cobalt
AMR	Annual Merit Review
ANL	Argonne National Laboratory
APEEM	Advanced Power Electronics and Electric Motors
ARPA-E	Advanced Research Projects Agency – Energy
ATF	Automatic transmission flui
B	Magnetic flux density
B-H	Magnetic hysteresis curve (magnetic flux density versus magneti field strength)
BEV	Battery electric vehicle
Br	Magnetic remanence
°C	Degrees Celsius (Centigrade)
CEMI	Clean Energy Manufacturing Initiative
CFD	Computational fluid dynamic
Co	Cobalt
CPES	Center for Power Electronics Systems
DC	Direct current
DF	Dissipation factor
DOE	U.S. Department of Energy
EDT	Electric Drive Technologies

EDV	Electric drive vehicle
EETT	Electrical and Electronics Technical Team
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
ESR	Equivalent series resistance
EV	Electric vehicle
FMEA	Failure mode and effects analysis
FCA	Fiat Chrysler Automobiles
Fe	Iron
FEA	Finite element analysis
Fe-Co	Iron-cobalt
FMVSS	Federal Motor Vehicle Safety Standards
FY	Fiscal year
GaN	Gallium nitride
GE	General Electric
H	Henry (the unit of electrical inductance)
H	Magnetic field strength
Hci	Intrinsic coercivity
HEV	Hybrid electric vehicle
HV	High-voltage
IAPG	Interagency Advanced Power Group
IC	Integrated circuit
IGBT	Insulated-gate bipolar transistors
IPM	Integrated permanent magnet
kHz	Kilohertz
kW	Kilowatt

L	Liter
µm	Micrometer (micron)
mm	Millimeter
MOS	Metal-oxide-semiconductor
MOSFET	Metal–oxide–semiconductor field-e fect transistor
MSR	Multi-speed range
NA	North American
nH	Nanohenry
Ni	Nickel
NNMI	National Network for Manufacturing Innovation
NRE	Non-rare earth
NREL	National Renewable Energy Laboratory
OBC	On-board charger
Oe	Oersteds
OEM	Original equipment manufacturer
ORNL	Oak Ridge National Laboratory
PBA	Planar-Bond-All
PE	Power electronics
PEI	Polyetherimide
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
PI	Principal Investigator
PM	Permanent magnet
PML	Polymer-multi-layer
R&D	Research and development
RE	Rare earth

SAE	Society of Automotive Engineers
Si	Silicon
SiC	Silicon carbide
TARDEC	U.S. Army Tank Automotive Research, Development and Engineering Center
TRL	Technology readiness levels
UTK	University of Tennessee, Knoxville
U.S.	United States
U.S. DRIVE	United States Driving Research and Innovation for Vehicle efficiency and Ene gy sustainability
V	Volt
VAC	Volt alternating current
VS	Vehicle Systems
VSATT	Vehicle Systems Analysis Tech Team
VTO	Vehicle Technologies Offic
WBG	Wide bandgap