3. Advanced Power Electronics and Electrical Machines Technologies

Advanced power electronics and electric motors (APEEM) that make up vehicles' electric drive system are essential to hybrid and plug-in electric vehicles. As such, improvements in these technologies can substantially reduce petroleum consumption in transportation, and help meet national economic, environmental, and energy security goals. Hybrid electric vehicles (HEVs) can reduce petroleum use compared to average conventional vehicles by as much as 50%, while plug-in electric vehicles (PEVs) extend these savings even further. The Vehicle Technologies Office (VTO) supports research and development to reduce the cost and improve the performance of innovative electric drive devices, components, and systems.

VTO's long-term R&D strategy recognizes that reducing the cost of electric drive is essential for consumer adoption. Because technology breakthroughs are necessary to achieve R&D goals, VTO funds research on APEEM to:

- Reduce cost, weight, and volume
- Improves performance, efficiency and reliability
- Develop innovative modular and scalable designs
- Improve manufacturability and accelerate commercialization

These improvements will help DOE meet the EV Everywhere Grand Challenge goal of making the U.S. the first nation in the world to produce plug-in electric vehicles by 2022 that are as affordable for the average American family as today's gasoline-powered vehicles.

VTO funds research to advance electric drive technologies in two key areas:

- power electronics
- electric motors

Within these areas, research efforts focus on:

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

In addition, VTO is also supporting research on propulsion materials to lower barriers to advanced power electronics and electric motors that face specific material limitations.

Subprogram Feedback

The U.S. Department of Energy (DOE) received feedback on the overall technical subprogram areas presented during the 2014 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 Vehicles Technologies Office (VTO) subprogram's activities. The subprogram overview questions are listed below, and it should be noted that no scoring metrics were applied. These questions were used for all VTO subprogram overviews.

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

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

Question 3: Were important issues and challenges identified?

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

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

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

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

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

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

Question 10: Has the program area engaged appropriate partners?

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

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

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

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

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

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

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

Subprogram Overview Comments: Susan Rogers (U.S. Department of Energy) – ape000

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

Reviewer 1:
The reviewer commented yes.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer remarked yes, the program area and strategy were adequately covered. However, it would be helpful to include a couple of overview charts including all of the relevant U.S. Department of Energy (DOE) cost, power density and performance metrics for the motor and power electric systems under development.

Reviewer 4:
The reviewer said yes, there are specific targets for inverter and motor in terms of cost. However, the reviewer would like to know where the cost targets for the converter and charger are.

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

Reviewer 1:
The reviewer responded yes, and observed a good balance between national laboratories, academics, industry and federal agencies.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer said yes, and recommended that DOE Vehicle Technologies Office (VTO) funding to DOE labs should have end applications and should be driven with this as one of objectives. The reviewer commented that even if it takes one or two more years for the project to complete, however, having the deployment of the developed technologies to end applications followed by commercialization could bring better results in long-term.

Reviewer 4:
The reviewer commented yes, the program appears to have an appropriate balance between near-, mid-, and long-term research and development (R&D) objectives. To accentuate this, the reviewer suggested an additional chart that bins the ongoing projects into these categories would be helpful during the presentation or as supplemental information to the reviewers.

Question 3: Were important issues and challenges identified?

Reviewer 1:
The reviewer commented yes.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer summarized that the important issues and challenges included the adoption of Wide Bandgap (WBG) solutions, reduction of rare earth metals, improved performance metrics, and reduced cost of electric drive systems. The challenges also included packaging, thermal management, and reliability improvements.

Reviewer 4:
The reviewer noted that the presentation identified as areas of increased emphasis of WBG devices and reduction or elimination of rare earth magnetic materials. Cost is the biggest challenge, with technologies identified to reduce cost. For this reviewer, the incumbent, off-roadmap, technologies would be of interest to learn more about (e.g., determine their importance).

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

Reviewer 1:
The reviewer commented yes.

Reviewer 2:
The reviewer stated yes.

Reviewer 3:
The reviewer said yes.

Reviewer 4:
The reviewer commented that although the overview presentation did not address solutions to each of the challenges, the projects included in the program address many of these challenges. Projects in other areas, however, are also complementary to these issues. The reviewer suggested that a chart describing the challenges, showing which specific projects address each challenges would be beneficial to the audience. The reviewer believed that it would be good if the chart included the complementary projects managed by the other areas.

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

Reviewer 1:
The reviewer said yes.

Reviewer 2:
The reviewer said yes, and commented that today's specific costs and targets were presented with the targets for 2020 and 2022 used for comparison.

Reviewer 3:
The reviewer observed that fiscal year (FY) 2013 progress was highlighted, but not in detail. From the two progress charts, it was difficult for this reviewer to extract significant improvements from the prior year. The slides did not emphasize all of the progress during the 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?

Reviewer 1:
The reviewer said that technologies have been identified to lower the cost size and weight of transportation power electronics. Lower cost, smaller size and weight power electronics is an enabler for electric drive vehicles (EDVs), which will reduce our dependence on foreign oil.

Reviewer 2:
The reviewer commented yes, in the focus areas of electrical machines and power converters, these projects certainly address VTO's broad problems and barriers.

Reviewer 3:
The reviewer said yes.

Reviewer 4:
The reviewer said yes.

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

Reviewer 1:
The reviewer said yes, and elaborated that Susan Rogers and Steven Boyd are well focused and are doing a great job managing the program and addressing VTO's objectives.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer commented yes.

Reviewer 4:
The reviewer stated yes.

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 as standouts those approaches that accelerate the manufacturing capability and mass production adoption of energy-efficient and cost-effective advanced power electronics and electric machine (APEEM) capacitor technologies into electric drive vehicles, such as electric vehicles (EVs), hybrid electric vehicle (HEVs), and plug-in hybrid electric vehicles (PHEVs). The reviewer identified as a standout the General Motors' (GM) program, and elaborated that GM is looking at applying technologies for future vehicles, which is an application of DOE developments. The reviewer also identified non-rare earth magnetic motors and the work at Ames National Laboratory, and elaborated that this future application will enable lower cost motors. Finally, the reviewer identified capacitors, and commented lower cost, smaller size and weight to enable lower cost, smaller size and weight power electronics.

Reviewer 2:
The reviewer commented yes, and elaborated that R&D work on high-temperature low-cost capacitors is suitable for silicon carbide (SiC)/gallium nitride (GaN)-based power electronics. The reviewer added that thermal management of inverter interconnects is very key to meet life, reliability and durability goals of power electronics parts and systems needed for vehicle applications, particularly for SiC/GaN inverter systems.

Reviewer 3:
The reviewer commented that the U.S. manufacturing of electric machines for the Chevrolet Spark EV that Susan highlighted is certainly a key success story for the program. The reviewer remarked that because many key HEV technologies are imported, it is great that a U.S. manufacturer has brought this technology in-house. The original equipment manufacturer (OEM) now has full ownership of the design and technology, and a complete understanding of the cost of this technology. Additionally, for this reviewer, it is a positive sign that production and sales of vehicles with this technology will increase in the near-term.

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

Reviewer 1:
The reviewer said yes, and elaborated that the projects certainly explore novel methods to achieve their specific objectives.

Reviewer 2:
The reviewer commented yes.

Reviewer 3:
The reviewer stated yes.

Reviewer 4:
The reviewer said yes.

Question 10: Has the program area engaged appropriate partners?

Reviewer 1:
The reviewer said yes, and commented that the program area includes numerous key players from industry and national laboratories and appropriate partners from academia and federal agencies.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer commented yes.

Reviewer 4:
The reviewer said yes.

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

Reviewer 1:
The reviewer said yes.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer said yes.

Reviewer 4:
The reviewer said yes, effectively. However, according to this reviewer, more could be done to bring the program area partners together to extend collaboration opportunities.

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

Reviewer 1:
The reviewer did not observe any gaps.

Reviewer 2:
The reviewer commented that the EV roadmap developed by the Electrical and Electronics Tech team, which are mostly vehicle OEMs, provides the direction for what industry is looking for. The APE VTO group works to enable technologies that fill the gaps in the roadmap.

Reviewer 3:
The reviewer said this was not applicable.

Reviewer 4:
The reviewer remarked that thermal management of inverter interconnects is lacking. Thermal management of inverter interconnects is a must to meet life and reliability goals, particularly for WBG inverters. The reviewer expressed concern that the lack of this information

may pose barriers to industries to adopt WBG inverter technologies developed by DOE laboratories, such as Oak Ridge National Laboratory (ORNL) and the National Renewable Energy Laboratory (NREL). The reviewer concluded that inverter and power device packaging concepts need to be proven out in vehicle applications and must meet vibration, thermal/power cycling needs, and reliability goals.

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

Reviewer 1:
The reviewer commented not observable.

Reviewer 2:
The reviewer noted that one of the key objectives in the overview included an integrated inverter into the motor housing. According to the reviewer, none of the projects seem to address this goal yet. It would be exciting to put together a partnering effort to fully explore this topic.

Reviewer 3:
According to this reviewer, maybe a slide on how the targets are set and who sets them, and the role of the EE Tech Team.

Reviewer 4:
The reviewer referenced comments in question number 12 addressing thermal management of inverter interconnects.

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

Reviewer 1:
The reviewer did not observe other areas to consider funding.

Reviewer 2:
The reviewer did not observe other areas to consider funding.

Reviewer 3:
The reviewer suggested encapsulation and sealant material research to IEC, Underwriters Laboratory (UL) standards, and meeting high voltage product safety requirements for medium- and high-voltage electric drives.

Reviewer 4:
The reviewer suggested high frequency, high current magnetics.

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

Reviewer 1:
The reviewer suggested an X-Prize approach for anyone who can demonstrate a process for growing a defect-free WBG wafer.

Reviewer 2:
The reviewer suggested that DOE-funded projects to DOE laboratories should be tied to end applications and that industry inputs should be collected at the start of the project rather than at a very late stage in the project. The reviewer believed that this would ensure that R&D activities undertaken by DOE laboratories are focused on applications and meet industry needs.

Reviewer 3:
The reviewer responded that this was not applicable.

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

Reviewer 1:

The reviewer suggested that project duration should be made to five years, and that an entity who receives DOE funding should be mandated to commercialize developed technology if cost and performance targets are met. The reviewer added that cost and performance targets should be tracked closely from the very beginning of the project and may be audited by a third party that has no conflict of interest with the principle investigator (PI) and his/her organization and partners in the project.

Reviewer 2:

The reviewer suggested that the program could consider partnering with other program areas to further explore the electric drive system integration with its mechanical transmission. This integration is the key to successful commercialization of these technologies.

Project Feedback

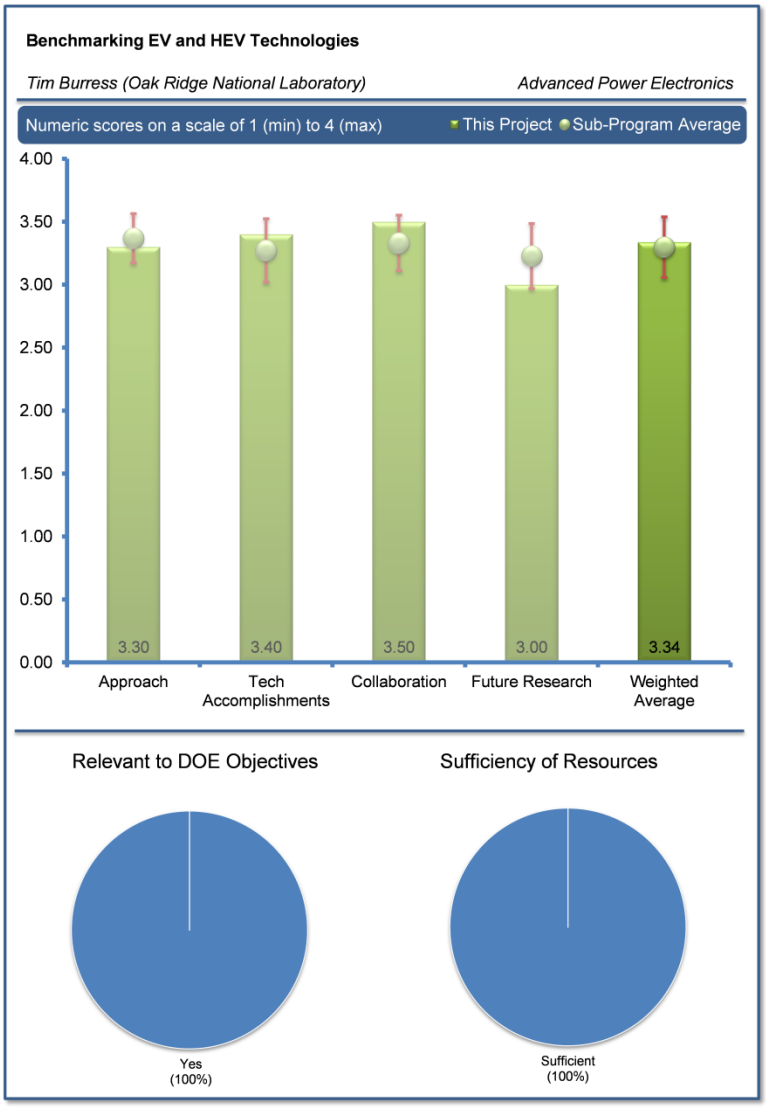
In this merit review activity, each reviewer was asked to respond to a series of questions, involving multiple-choice responses, expository responses where text comments were requested, and numeric score responses *(on a scale of 1.0 to 4.0)*. In the pages that follow, the reviewer responses to each 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.

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
† Benchmarking EV and HEV Technologies	Tim Burress (Oak Ridge National Laboratory)	3-11	3.30	3.40	3.50	3.00	3.34
Permanent Magnet Development for Automotive Traction Motors	Iver Anderson (Ames)	3-14	3.58	3.42	3.50	3.08	3.43
High-Temperature Air-Cooled Power Electronics Thermal Design	Scot Waye (National Renewable Energy Laboratory)	3-18	3.14	3.14	3.21	3.00	3.13
† Characterization, Modeling, and Reliability of Power Modules	Allen Hefner (National Institute of Standards and Technology)	3-22	3.42	3.25	3.08	3.08	3.25
Development of SiC Large Tapered Crystal Growth	Philip Neudeck (National Aeronautics and Space Administration)	3-25	2.83	2.33	2.67	2.50	2.52
North American Power Electronics Supply Chain Analysis	Christopher Whaling (Synthesis Partners)	3-27	3.70	3.50	3.70	3.40	3.56
Reliability of Electrical Interconnects	Doug DeVoto (National Renewable Energy Laboratory)	3-30	3.29	3.14	3.14	2.93	3.15
† Two-Phase Cooling of Power Electronics	Gilbert Moreno (National Renewable Energy Laboratory)	3-33	3.17	3.17	3.08	3.08	3.15
Next Generation Inverter	Sean Gleason (General Motors LLC)	3-36	3.30	3.20	3.60	3.40	3.30
Unique Lanthide-Free Motor Construction	Jon Lutz (UQM Technologies, Inc.)	3-39	3.20	3.20	3.30	3.20	3.21
Alternative High-Performance Motors with Non-Rare Earth Materials	Ayman El-Refaie (General Electric Global)	3-43	3.33	3.42	3.42	3.08	3.35
Power Electronics Packaging	Zhenxian Liang (Oak Ridge National Laboratory)	3-47	3.50	3.50	3.29	3.29	3.45
Inverter R&D	Madhu Chinthavali (Oak Ridge National Laboratory)	3-52	3.70	3.50	3.50	3.60	3.56
Converters and Chargers	Gui-Jia Su (Oak Ridge National Laboratory)	3-55	3.33	3.33	3.33	3.67	3.38
Advanced Low-Cost SiC and GaN Wide Bandgap Inverters for Under-the-Hood Electric Vehicle Traction Drives	Adam Barkley (APEI, Inc.)	3-58	3.50	3.63	3.38	3.50	3.55
High Temperature DC-Bus Capacitors Cost Reduction and Performance Improvements	Angelo Yializis (Sigma Technologies International)	3-61	3.50	3.25	3.38	3.38	3.34
High Performance DC Bus Film Capacitor	Dan Tan (GE Global Research)	3-64	3.25	3.25	3.50	3.38	3.30
Cost-Effective Fabrication of High-Temperature Ceramic Capacitors for Power Inverters	Balu Balachandran (Argonne National Laboratory)	3-67	3.38	3.13	3.50	3.25	3.25

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Scalable Non-Rare Earth Motor Development	Tim Burress (Oak Ridge National Laboratory)	3-70	3.50	3.30	3.30	3.40	3.36
† Performance and Reliability of Bonded Interfaces for High-Temperature Packaging	Doug DeVoto (National Renewable Energy Laboratory)	3-73	3.33	3.25	3.17	3.17	3.25
Convective Cooling and Passive Stack Improvements in Motors	Kevin Bennion (National Renewable Energy Laboratory)	3-76	3.50	3.42	3.42	3.42	3.44
Overall Average			**3.37**	**3.27**	**3.33**	**3.23**	**3.30**

Note: † denotes poster presentations.

Benchmarking EV and HEV Technologies: Tim Burress (Oak Ridge National Laboratory) - ape006



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 agreed that this project helps with program planning and the establishment and verification of all DOE 2020 targets. The reviewer also noted that this program was well-focused on the barriers and targets.

Reviewer 2:

The reviewer acknowledged that the benchmarking effort allows the U.S. industry to understand the current suppliers' capability and also helps to set up the next generation design target.

Reviewer 3:

The reviewer applauded the excellent approach and work; adding that it was nice that the researchers showed the history and progression from previous years (FY 2008) to the current work (FY 2013). The reviewer also mentioned that incorporating an evaluation of not just main inverter, but also the recent charger developments, was a nice benefit and addition.

Reviewer 4:

The reviewer said that it seemed like a good approach; although widespread dissemination of the data was important, but it did not seem to be a priority.

Reviewer 5:

The reviewer commended that PI had done an excellent job of examining the performance and operational characteristics during teardown of sub-systems. However, the reviewer cautioned that the team overall was not doing well to conduct a more valuable analysis for assessing design, packaging, and fabrication innovations. For example, the team observed that the 2013 Toyota Camry powertrain control unit power density and specific power were the highest without conducting further root cause analysis. The reviewer concluded by stating that in short, the team had done a great job for the second overall objective, but not so well for the first and third objectives.

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 toward DOE goals.

Reviewer 1:

The reviewer stated that this work provided a valuable benchmark for progress towards the DOE goals.

Reviewer 2:
The reviewer commented that the comparison of DOE targets, over the time of the various teardowns, was well done and provided an evolution of the technology.

Reviewer 3:
The reviewer observed very nice work here; however suggested that additional inputs on specific barriers and opportunities for R&D work would additionally compliment this area.

Reviewer 4:
The reviewer praised that the team had done a great job for the second overall objective described in Slide 3, but not so well for the first and third objectives.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer asserted that the work seemed well-integrated with other efforts at ORNL and at other national laboratories. The reviewer, however, suggested that it would be valuable to release data more widely.

Reviewer 2:
The reviewer noted the nice expansion in this area. The reviewer also mentioned the modeling work and that the presenter highlighting opportunities was a well-stated need. The reviewer suggested that perhaps more input from component suppliers could be sought, although the reviewer presumed this had been pursued and suppliers were hesitant to provide detail on new products or products in development. Instead, the reviewer suggested that if a product was in production, however, there should be less to protect as global reverse engineering would be possible after these products were sold to the general public.

Reviewer 3:
The reviewer emphasized that it required many skill sets to reverse engineer the controls and the hardware to allow testing and analysis of someone's else hardware; however the team that is brought together gets the job done. The reviewer also suggested that perhaps there could be some leveraging by using some of the work that is being done by commercial teardown facilities, like a2mac (there are others) to do the teardowns. This would allow ORNL to focus more of the work on the analysis and controls of the hardware. This person noted that the question that would need to be answered if the commercial teardown information could be provided to a wider audience.

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

Reviewer 1:
The reviewer agreed that the project seemed to be very well-aligned, and also pointed out that the BMW i3 looked to be a nice candidate for evaluation. The reviewer looked forward to next year's presentation.

Reviewer 2:
The reviewer described that the next steps appeared to be looking at whatever came next, from a non-American vehicle original equipment manufacturer (OEM). This person remarked that it would be useful to have more of a strategy for what gaps needed to be addressed, though. The reviewer inquired about what is most valuable to learn next, rather than what is available next.

Reviewer 3:
The reviewer noted that the future work is a continuation of the present work. However, the reviewer highlighted that the relevance statement on the summary slide indicates that the core function of this project is to confirm power electronics and electric motor technology status and identify barriers and gaps to prioritize/identify R&D opportunities. The reviewer noted that, although barriers and targets were seen, this reviewer did not see a Barriers and Gaps slide. Furthermore, this reviewer reported that no gaps were mentioned.

Reviewer 4:
The reviewer commented that there is no plan to conduct more valuable analysis other than simply teardown and do some measurement.

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

Reviewer 1:
The reviewer agreed that understanding the factors which will reduce cost of EDV will lead to greater sales of these vehicles, and thereby decrease petroleum use.

Reviewer 2:
The reviewer highlighted that the work was very relevant and well-presented. The reviewer noted that the material shows a living timeline of the technical milestones and industry offerings that are relevant to this work.

Reviewer 3:
The reviewer asserted that knowing the state-of-the-market of transportation power electronics helps to establish targets of where the technology is going, and how fast it is changing. The reviewer explained that this helps the recipients to know this information to improve their hardware and to better compete in the marketplace by improving and lowering the cost of their products to enable the EDV marketplace.

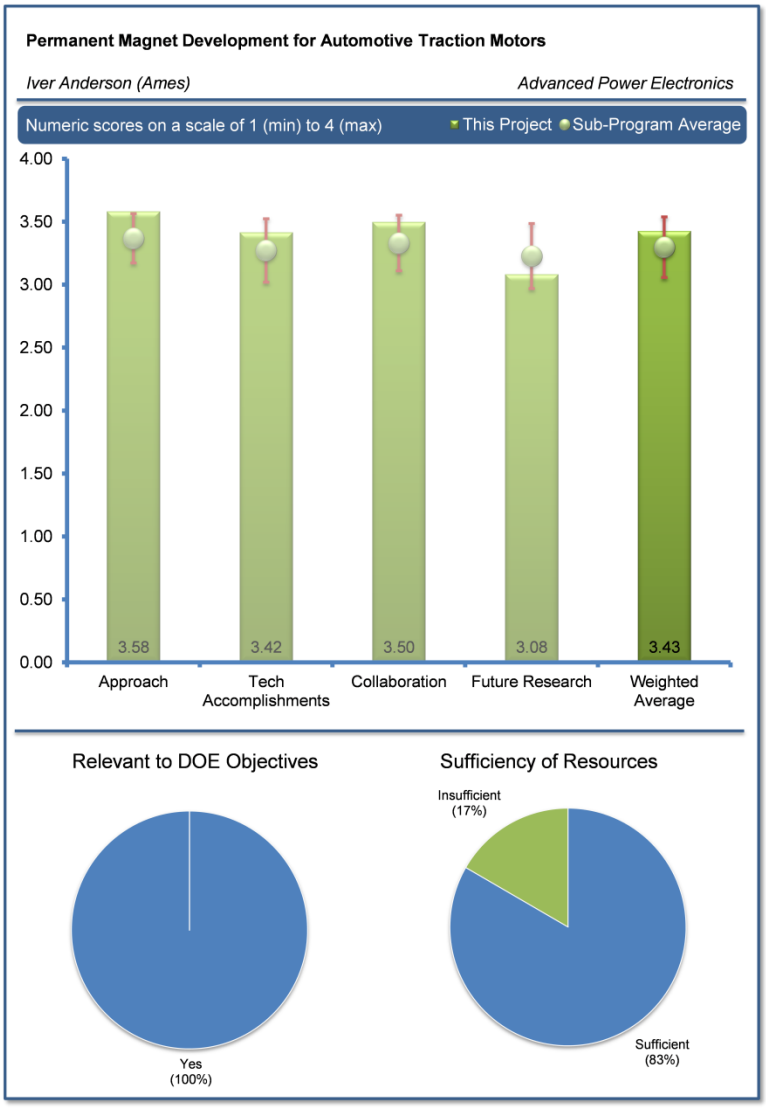
Question 6: Resources: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer indicated that this was not discussed specifically, but the resources seemed to be sufficient.

Reviewer 2:
The reviewer explained that it requires many skillsets to reverse engineer the controls and the hardware to allow testing and analysis of someone's else hardware; the team that is brought together gets the job done.

Reviewer 3:
The reviewer noted that the resources are well-suited to the tasks and that the use of the national laboratories seems to be well-aligned. The reviewer suggested that additional industry resources would be an excellent addition, but the hesitancy of industry participants is well-understood. The reviewer looked forward to next year's presentation.

Permanent Magnet Development for Automotive Traction Motors: Iver Anderson (Ames) - ape015



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:

Although this reviewer cannot evaluate this project from the perspective of a materials expert or metallurgist (which this reviewer is not); the reviewer spent time researching the subject matter in brief prior to the review and saw the technical approach and diligence to this effort to be beyond extraordinary. The reviewer asserted that the PI's depth of knowledge is truly exceptional.

Reviewer 2:

The reviewer noted that the approach thus far has been to cast a rather broad net to look for permanent magnet (PM) improvements (low rare-earth [RE] content and short- and long-term zero-RE content magnets). The reviewer explained that the individual research areas within that effort have been both theoretical/computational and experimental which the reviewer thought has been an excellent approach, and very appropriate for this stage.

Reviewer 3:

The reviewer summarized that the project seeks to achieve comparable PM performance without use of RE materials. The reviewer noted that the following three paths were investigated: near-term RE magnets with reduced dysprosium (Dy); near-term non-RE magnets; and long-term non-RE magnets.

Reviewer 4:

The reviewer agreed that the research targets the appropriate tasks (i.e., heavy RE element elimination and non-RE activities). The reviewer noted that research in the AlNiCo area could yield useful materials if intrinsic coercivity is increased, even at the expense of residual induction and if these improvements are applicable to "motor-sized" magnets.

Reviewer 5:

The reviewer concluded that the team was doing an excellent job in a very fundamental research area for both simulation and testing. The reviewer suggested that the team be aware of the gap between simulation and testing in multi-scale (nano-, micro-, and macro-) levels, especially where direct testing is not possible. In addition, a great amount of process uncertainty (e.g., AlNiCo processing) should be considered and the influence to magnetic properties should be studied. Ideally, the team needs expertise in material uncertainty quantification and propagation analysis, and multi-scale model validation and verification, which will greatly help address the second and third remaining challenges shown in Slide 22. The reviewer offered that a recent publication (citation provided below) could be a good reference for addressing this issue. The papers' authors studied the gap between simulation and testing for mechanical properties of the carbon nanotube by considering the material processing uncertainty. The reviewer suggested that although the research was not

for coercivity analysis, the idea in that paper could be adopted in this project. However, the reviewer acknowledged that given the remaining time left for this project (September 2014 finish), it seemed impossible to address the remaining challenges. This reviewer also provided the following reference: Xi & Youn, Predictive carbon nanotube models using the eigenvector dimension reduction (EDR) method, Journal of Mechanical Science and Technology 26 (4), 1089-1097, 2012.

Reviewer 6:

The reviewer explained that anisotropic die-upset neodymium-iron-boron (Nd-Fe-B) magnets can reach a $(BH)_{max}$ of slightly above 40 megagauss-oersteds (MGOe). In comparison, sintered Nd-Fe-B can reach $(BH)_{max}$=52-54 MGOe and Hci=12 kOe without any dysprosium (Dy) addition. The die upset magnets have a higher temperature coefficient of coercivity than the sintered counterparts. A possible increase in Hci due to the nanocrystalline structure in die upset magnets is counterbalanced by the platelet shape of the grains with an out of plane texture. The reviewer commented that an Hci of less than 10 kOe for compositions, even containing 1.3 wt% or 3 wt% of Dy, is not particularly notable. The reviewer stated that this low Hci juxtaposed with the loss of squareness of the demag curve in the magnet samples with less Dy results in a rather low $(BH)_{max}$ of 17.2 MGOe. The reviewer offered that it would be interesting to know the value of the saturation magnetization since the remanence is low. In other words, the reviewer wanted to know if this single stage hot deformation of Nd-Fe-B induced a good texture without requiring the intermediary hot pressing step. The reviewer observed that the role of zinc (Zn) in increasing the coercivity seemed interesting to be explored. The reviewer also thought it would be interesting to know what the mechanism of Zn migration to the grain boundaries was (for example, could it be via Nd-rich phase, or could it be squeezed out.). The reviewer also wondered what the mechanism was under which the coercivity is maintained at the same value when decreasing the Dy content from 3.0 wt% to 1.3 wt%. The reviewer cautioned that prediction of high coercivity in AlNiCo for Fe-Co (or rather Fe or Co as shown for the zero-temperature case in the presentation slides) rod diameter below 20 nm may be difficult to put in practice due to the difficulty of prediction of optimum magnetic annealing temperature. The reviewer suggested that using a gas-atomized powder precursor should prove to have a significant advantage over the conventional process, in order to economically produce new grades with better performance.

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 toward DOE goals.

Reviewer 1:

The reviewer reported that the results to date have given a good understanding of underlying mechanisms for coercivity in AlNiCo magnets, and potential paths forward for new alloys and processing.

Reviewer 2:

The reviewer commented that some targets that were established during the last meeting (e.g., 300% AlNiCo coercivity improvement) have not been achieved and that the bar has been lowered. The reviewer acknowledged that this was the nature of advanced science, but stated that it was still disappointing to those who would be able to make good use of these achievements. This reviewer still applauded the focus and work on the right goals, and that the researchers' understanding that stretch goals were inherently difficult to achieve.

Reviewer 3:

The reviewer noted that this effort has resulted in new methods for improving PM materials. The reviewer pointed out that the progress related to AlNiCo 8H coercivity was very encouraging and that the specialized annealing/heat treatment profiles that were developed for AlNiCo 8H show promise to further improve the material's magnetic properties. The reviewer also asserted that the new electric machine designs, optimized for the low coercivity properties of AlNiCo, from the project partners are also an outcome of this research. This person acknowledged that the project has resulted in an impressive number of technical publications. The reviewer questioned, with the project nearing completion (96%) combined with previous years of funding, whether any of the project findings have been transitioned to commercial PM production processes.

Reviewer 4:

The reviewer reported that the technical milestones for the magnetic performance of the new magnets to be developed were not very well-defined. The reviewer commented that milestone for 2014 on AlNiCo were reported on schedule, and seemed to be towards the main goal of maintaining, or enhancing, the performance of AlNiCo 8 at a 30% reduction in cost associated with a 40% reduction in Co

content. The reviewer described that the magnetic performance reported is promising, if it is for the composition with 40% less Co. Good progress has been made towards enhancing the coercivity and energy product, although not yet at the level of the commercial magnets. Demag curve tests at higher temperatures would have been useful in assessing the thermal stability of the AlNiCo samples with the highest coercivity. The reviewer explained that it would have been good to have known the size of the magnet samples and the level of result reproducibility. This person also thought that a more clear correlation between the microstructure, processing conditions, and the achieved magnetic properties would have given a clearer picture on the feasibility of reaching the desired optimum microstructure.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer expressed that there appeared to be very good communication with both industrial and university partners, and a willingness to acknowledge and use progress from wherever it came. The reviewer also applauded that it was great to see the recognition given to all collaborators.

Reviewer 2:
The reviewer indicated that, apparently, there is core collaboration in this area, while respecting independent in the application between several of these DOE programs on this subject matter. The reviewer pointed out that this synergy is necessary to achieve the objectives in motor development.

Reviewer 3:
The reviewer observed that the engagement with formal and informal collaborators continues to be strong; also suggested that the researchers please continue to stay connected with industry.

Reviewer 4:
The reviewer described that there are several key partners in this work, including Arnold Magnetics, University of Nebraska-Lincoln, University of Maryland, and ORNL, as well as numerous industry and academic collaborators. The reviewer also mentioned that the project included annual Beyond Rare Earth Magnets workshops to share results and coordinate future research with the project collaborators.

Reviewer 5:
The reviewer suggested that it may be a good idea to analyze the spinodal decomposition mechanism when involving Fe_8CoMo phase, instead of FeCo, and to also model the extrinsic magnetic properties of such a morphology (i.e., FeCo rods replaced by Fe_8CoMo with K~20- 30 miueV/atom, as determined by density functional theory and GA).

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

Reviewer 1:
The reviewer agreed with the overall recommendations for future work, emphasizing experimental verification of alloys/mechanisms suggested by computational models, and attention to bulk processes that would increase coercivity of AlNiCo on a macro-scale.

Reviewer 2:
The reviewer mentioned that the program was winding down and will hopefully continue through another program. The reviewer requested that if the work continues, to please continue working on AlNiCo and FeCo magnets, Co reduction, and to look at the mechanical properties associated with the research. The reviewer concluded by stating that improved AlNiCo mechanical properties (i.e., reduced brittleness) are desired.

Reviewer 3:
The reviewer stated that the FY 2014 future plans are comprehensive and very well-defined, as necessary, in order to assure a good progress for the project. The reviewer cautioned that the extent of these plans is significant, however, is far beyond one year given the achievements since the beginning of the project. The reviewer agreed with the previous reviews on the need for concrete target magnetic parameters, which can be formulated under different scenarios (e.g., [i] 40% reduction of Co and Fe-Co in new AlNiCo grade: Hci = x, BH_{max} = y, [ii] Fe_8CoMo with magnetocrystalline anisotropy instead of Fe-Co rods with shape anisotropy: Hci=x, BH_{max}=y, [iii] bulk $HfCo_7$ + Fe-Co: Hci = x, BH_{max} = y, and [iv] others).

Reviewer 4:
The reviewer summarized that the key challenge was identified that AlNiCo coercivity levels and maximum energy product values achieved are insufficient to permit AlNiCo magnet use in an advanced PM traction drive motor. Given that finding, the reviewer inquired about the values that would be required for adoption, and how closely the planned FY 2014 work would approach the needed metrics.

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

Reviewer 1:
The reviewer stated that PM motors are still the most efficient motor types, and high-energy PMs are the key components of these motors. The reviewer added that it has been well-documented that magnets using heavy REs (i.e., the current state-of-the-art) will soon be in short supply, so alternative and less expensive compositions and processes must be identified.

Reviewer 2:
The reviewer explained that dependence on heavy REs specifically, and all REs in general, may derail electrification activities if the sources of these materials are unstable.

Reviewer 3:
The reviewer indicated that the electrical machines that are developed that use this technology support further vehicle electrification and hybrid-electric applications, which will result in less fuel consumption. The reviewer explained that less RE content will significantly reduce the cost of advanced electric machines, which will contribute to increased adoption.

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

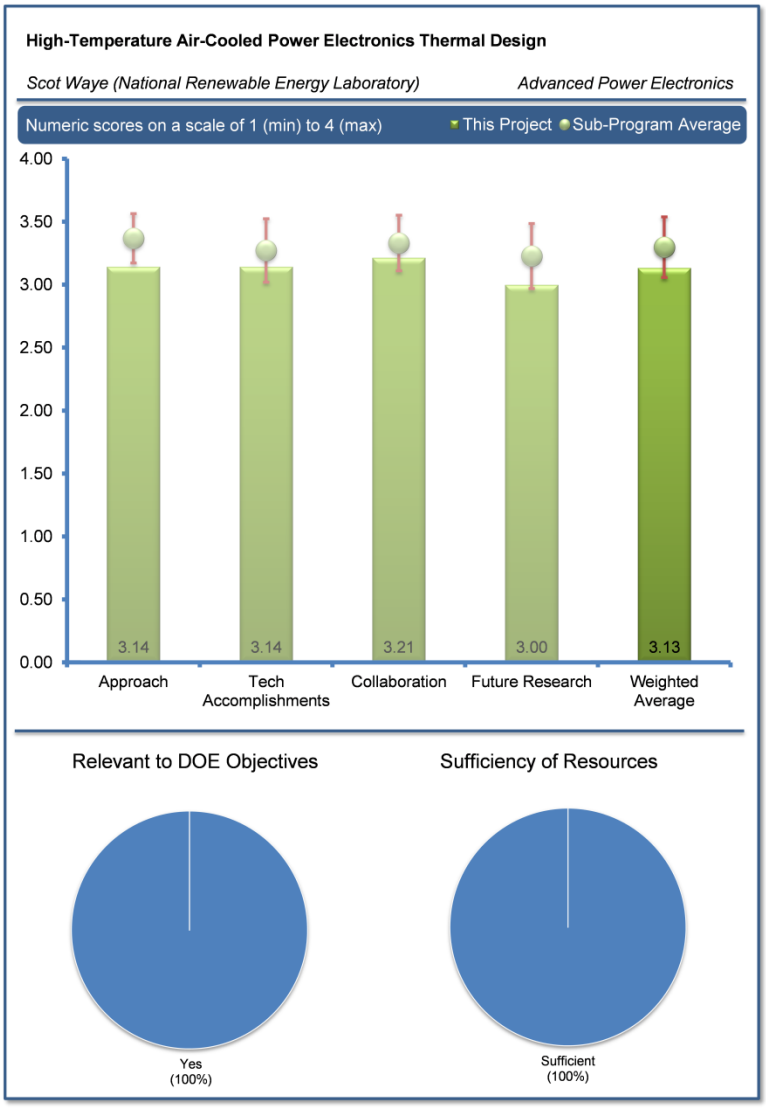
Reviewer 1:
The reviewer stated that the resources for this program are appropriate.

Reviewer 2:
The reviewer noted that this project is in its final year and has had very significant progress throughout its duration; a lack of resources was not apparent.

Reviewer 3:
The reviewer doubted that the stated future work will be accomplished within the remaining project time because this project is already 96% complete. The reviewer, however, thought the right collaborators were engaged.

Reviewer 4:
The reviewer pointed out that some of the tasks have been aborted due to insufficient funding. In this reviewer's opinion, the funds for this extended project should have been sufficient, but the reviewer acknowledged not knowing the operating costs at the Ames Laboratory (Ames). The reviewer agreed that the team has the needed available infrastructure to perform the work.

High-Temperature Air-Cooled Power Electronics Thermal Design: Scot Waye (National Renewable Energy Laboratory) - ape019



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 commented that the scalability to higher power levels may have issues that were not well-identified here.

Reviewer 2:

The reviewer pointed out that the cooling approach was most relevant to power systems based on WBG devices and systems. This person also voiced that the issue of air filtration did not appear to have been addressed. Once addressed, the reviewer explained that there was a need to address intake air filtration requirements and the impact on the fan/blower power requirements. The reviewer suggested that it would be useful to have a cost comparison of a full-up air-cooled system versus a full-up liquid-cooled system where the cost for each system would include all components required to enable the cooling system. The reviewer inquired about the location of an air-cooled system under the hood and the air intake and discharge ducting issues for a vehicle.

Reviewer 3:

The reviewer agreed that the development of a 10 kilowatt (kW) (ORNL design) air-cooled (NREL design) inverter is good start, however the reviewer cautioned that its scalability for 30 kW (continuous) / 55 kW (peak) needs significant testing to meet the requirements of a commercial application. The peak loading duration (18 seconds) is known; however the frequency that this peak loading occurred at was not clear from the presentation or project report. The project evaluator also cautioned that the researchers, assuming that external ambient and/or cabin air shall be available for air-cooling, could place extra burden on cabin environment management systems and that customers may not be willing to accommodate required changes on vehicle platform. The reviewer did mention that the collaborative activities between NREL and ORNL could bring useful results.

Reviewer 4:

The reviewer agreed that the overall project goals were pertinent to DOE goals; however mentioned that the premise that air-cooling for work for high-power traction inverters in the underhood environment is of concern. The reviewer pointed out that the state-of-the-art slide indicated a single high-power inverter in a vehicle that was not in production, while one could look under the hood of any EV today and find liquid-cooled power electronics. The reviewer described that the use of air-cooling on lower power systems (with values under 15 kW) had been done with the electronics packaged in the trunk and having access to conditioned cabin air. The reviewer observed that the team had done a good job in identifying the advantages and disadvantages/challenges of air-cooling, but indicated the need to add audible noise control (not just the fan, but also the air ducting and exhaust) to the challenge list. The reviewer voiced that

the specific goals identified for FY 2014 were very appropriate for this project. The reviewer added that a 10 kW power stage is achievable, and within the range that air-cooling makes sense, and could be used to obtain reasonable performance data for extrapolation to higher power levels.

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 toward DOE goals.

Reviewer 1:
The reviewer stated the technical details were well-presented.

Reviewer 2:
The reviewer applauded that proving out an air-cooled inverter that is projected to meet 2020 targets is commendable. The reviewer suggested that hot spots in the temperature profile of the 10 kW inverter's parts as a function of airflow rate should be useful data at 100%, 50%, and 25% of the peak rated loads. The reviewer explained that this data could be used for ANSYS simulation to produce the design data that is required to scale the power level to the targeted 30 kW (continuous) and 55 kW (peak) rating.

Reviewer 3:
The reviewer voiced that the analysis and modeling results showed promise for meeting the DOE goals based on the assumptions made. The reviewer was concerned with whether the assumptions are realistic and if the scaling from 10 to 55 kW is achievable. The reviewer remarked that the underhood environment of a hybrid vehicle, with the internal combustion engine operating, can be very hot and dirty at times, which will have a large impact on the quality of the cooling air available to an underhood mounted traction inverter. The reviewer suggested that this might be more appropriate for an EV which does not have an internal combustion engine to contend with. The reviewer acknowledged that the advances in the design of the heat exchanger and the module are excellent. One concern the reviewer noted was how the connections to the power in/out and the control signals would be made while still keeping the other parameters (e.g., inductance of the bus and attachment to the bus capacitor) acceptable. The reviewer suggested that one method could be to mount the bus capacitors on the bottom side of the heat exchanger in order to provide cooling for it.

Reviewer 4:
The reviewer suggested that the project could study different packaging alternatives, types of fans, and inverter/cooler interface options.

Reviewer 5:
In response, the reviewer inquired about the following: the inlet air design temperature (42.5°C or 45.0°C); the impact of higher inlet air temperature on system performance and electronic operating temperature; the maximum practical inlet air temperature; and the impact on power module life and reliability considering the range of air inlet temperature that would need to be accommodated (i.e., an Alaska winter operation versus a southern United States summer operation).

Reviewer 6:
The reviewer commented that the presentation was missing experimental data to support system level performance improvement over the liquid-cooled approach.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that collaboration among team members was very good and was encouraged to see the team reaching out to vehicle OEMs and Tier 1 suppliers regarding challenges/issues with air-cooling. Continued encouragement of this collaboration was expressed by the reviewer.

Reviewer 2:
The reviewer asserted that the collaboration between NREL and ORNL was great and commendable. This person also mentioned that an industrial partner could be desired to have to test verify the usefulness of developed 10 kW inverter with air-cooling.

Reviewer 3:
The reviewer suggested that the effort would benefit from the participation of an inverter manufacturer regarding air-cooling system design specification, packaging, and integration relative to the inverter electronic system. The reviewer also mentioned that the effort would benefit from the participation of a vehicle manufacturer regarding system specifications and under the hood integration (i.e., the reviewer wanted to know if there was adequate space within the engine compartment to integrate overall power module system).

Reviewer 4:
The reviewer noted the project team had a lack of collaboration with an automotive Tier 1 supplier and OEM.

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 summarized that the PI identified the remaining challenges and barriers as including location of inverter under the hood. The reviewer noted that it would be a commendable accomplishment if this was achieved. The reviewer explained that power loss and thermal management requirements for inverter's parasitic losses were good objectives for future research.

Reviewer 2:
The reviewer asserted that if the air-cooled system proof-of-concept testing demonstrated that the approach could meet the program goals, then the future work should include an integrated air-cooled inverter system that is installed and tested in a vehicle.

Reviewer 3:
The reviewer reinforced that the researchers needed to address the potential issues with scalability to higher power levels.

Reviewer 4:
The reviewer noted that the researchers continuing to follow the plan should result in meeting the goals of the project. The reviewer commented that it will be difficult to meet the 12 kW/L goal with a 10 kW system when the estimates for the capacitor are greater than 1 L. However, the performance and packaging density required for a 55 kW can be extrapolated from the test results. The reviewer reported that building a system test bench and representative power modules will be a valuable step for providing data to support the final conclusions. The results of the parasitic loss testing on the new bench and the testing of the 10 kW power stage and finally an inverter will provide valuable insight into the future of air-cooled power electronics. The results of the parasitic loss testing on the new bench and the testing of the 10 kW power stage, and finally an inverter, will provide valuable insight into the future of air-cooled power electronics. The reviewer suggested the researchers should add some audible measurement capabilities and the ability to add duct work (versus flexible hose to direct the air flow) into the test bench design, but this could be done as a future project. The reviewer expressed interest in seeing an analysis of the efficiency predictions as a function of operating temperature. This would answer questions such as what happens to the losses as the device temperature exceeds 150°C and the cooling air temperature increases. The reviewer stated that interior air can be considered to be conditioned, but cautioned that it still gets quite warm when sitting in the sun with the vehicle off, so takes some time to cool to 25°C or so.

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

Reviewer 1:
The reviewer stated that the work was consistent with DOE objectives.

Reviewer 2:
The reviewer indicated that efficient cooling is a major factor in the overall efficiency of EVs.

Reviewer 3:
The reviewer affirmed that if the packaging density and power density targets are met and the overall cooling system design is simplified, this could result in size and weight reductions of electric drivetrains for vehicle applications. This size reduction should result in fuel consumptions reductions over the life of the product.

Reviewer 4:
The reviewer agreed that this task was relevant to the stated DOE objective of petroleum displacement as it was providing an alternate cooling method that may prove to be more cost-effective in some vehicle implementations.

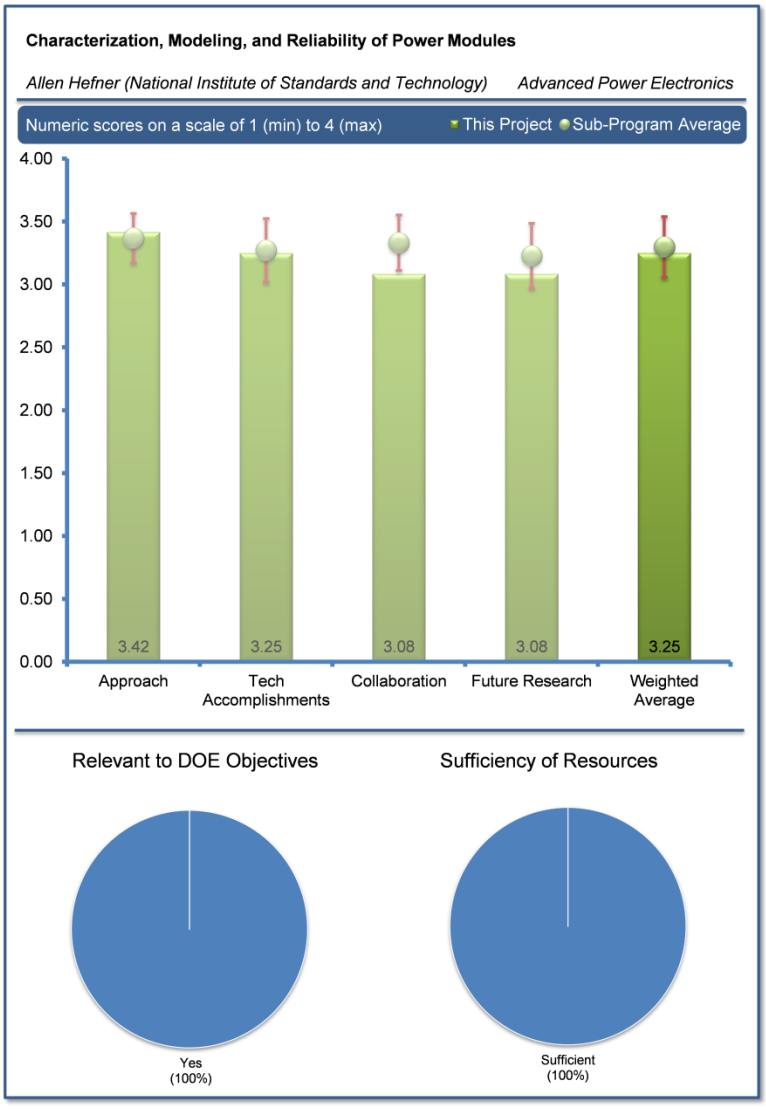
Reviewer 5:
The reviewer explained that air-cooling was simpler than liquid-cooling, therefore there was cost saving benefits if it was proved to work.

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 had been sufficient for the project to date as the progress had been as planned.

Reviewer 2:
The reviewer indicated a desire to have an industrial partner to test the developed technology to verify the performance in a real-world application.

Characterization, Modeling, and Reliability of Power Modules: Allen Hefner (National Institute of Standards and Technology) - ape026



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:

From the poster presentation, it appeared to this reviewer that the project tasks were on track and that the approach could overcome identified barriers.

Reviewer 2:

This reviewer noted that the project was well-designed, took advantage of existing simulation tools/methods, and was adding to the theoretical understanding of stresses acting upon power modules used in EV applications with a goal of improving the performance of these devices. The project was using two different power models for modeling and testing as well as investigating new measurement techniques and products.

The project plan is detailed enough that it was easy to see the interactions and was put together in a logical format. The plan plus the list of milestones/decisions enabled a better understanding of the tasks and progress being made on this project.

The projects goals were very noble and valuable, but to be useful to industry at large, they needed to be combined into an "analysis package" that could be used during the development of new power electronics. The reviewer said that hopefully the combination of this task and the NREL bonded interface material (BIM) task collaboration shown on the plan as future work for this year would be a start for this package.

Reviewer 3:

To this reviewer, the program was focused on developing modeling tools for inverters and converters. The reviewer added that it was unclear if the work would produce a computer design/simulation tool that could be used to evaluate different inverter and converter designs relative to performance and reliability.

Reviewer 4:

To this reviewer, validation work could be done in a significantly more systematical way rather than comparing the test measurement with simulation results. In addition, the reviewer was suspicious that the listed "validation results" may be calibration results, which means that some mysterious model parameters are tuned to fit the test measurement. For typical validation work, it is necessary to quantify the validity of the model, which is missing in this project. These issues are important because reliability analysis/prediction (Slide 26) relies on uncertainty characterization and quantification that comes from not only loading uncertainty (e.g., thermal cycling)

but also parameter and model uncertainty. Otherwise, reliability prediction may not be actually credible. This reviewer also included the following systematic model validation references: Youn et al., 2011, A hierarchical framework for statistical model calibration in engineering product development, Computer Methods in Applied Mechanics Engineering; Xi et al., 2013, Model bias characterization in the design space under uncertainty, International Journal of Performability Engineering; and Xi et al., 2013, State of Charge Estimation of Lithium-ion Batteries Considering Model and Parameter Uncertainties, Annual Conference of the PHM Society.

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 toward DOE goals.

Reviewer 1:
The reviewer observed that the project had very good progress to date. Test data and simulation results matched, new test methods had been developed and models of the test fixture created. These advances had enabled characterization of two different module type's thermal performance during short circuit conditions. Basically, the goals of the project had been met per the plan – integration with the NREL package task in progress.

The reviewer added that the results to date indicate that this approach would be very useful during the early design phase of an EV power module/inverter development project. If this project was reduced to a set of analysis software with test equipment the reviewer believed it would significantly reduce the design iterations and/or over designing of the power module/cooling method interface and perhaps enable the optimum sizing of switching devices within the module thus reducing size and cost.

Reviewer 2:
This reviewer commented that thermal cross-coupling effects between devices in the power module packages could be quite useful for real-world application. Thermal network, parameter extraction, modeling and measurement related tasks and completion of these tasks is also quite useful if the developed method is adopted for design and performance verification in real-world applications.

Reviewer 3:
According to this reviewer, the presentation contained a significant amount of detailed information regarding the electro-thermal-mechanical modeling of power modules. It would be useful to show how the electro-thermal-mechanical simulation would be applied to the evaluation of a generic inverter or converter. It would be useful to show how the modeling would be used to conduct a trade-off study of a generic inverter or converter to support the assessment and optimization of electrical efficiency, package thermal performance, system reliability, and system cost.

Reviewer 4:
The reviewer noted that the project completed electro-thermal simulations of SiC WBG modules, which can be used to simulate computer designs.

Reviewer 5:
This reviewer stated that it would be good to benchmark the test data versus the simulation data in order to verify the effectiveness of the model.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer noted that the collaboration among team members was very good based on the results shown; it would have been rated excellent, but no reason was given for the deleted tasks.

Reviewer 2:
This reviewer observed that the project investigators at the National Institute of Standards and Technology had collaborated with Delphi on electro-thermal-mechanical tasks and planned to collaborate during the remainder period of the project with NREL on reliability aspects of the project.

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

Reviewer 1:
This reviewer noted that significant work may be needed to complete the reliability investigation. This requires collaborative efforts with NREL and could fulfill project objectives to investigate module reliability.

Reviewer 2:
According to the reviewer, future work per the plan is needed to complete the goal of this project. Once the complete module can be modeled and performance simulated the addition of more capabilities per the proposed future work on a separate task would be valuable. The reviewer suggested to start implementation now of the last item on that slide (i.e., utilize the advanced technology electro-thermal network simulation tools developed by this project to support industry transition of the technologies into products).

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

Reviewer 1:
This reviewer stated that the WBG SiC models would allow engineers to simulate designs before prototyping the circuits.

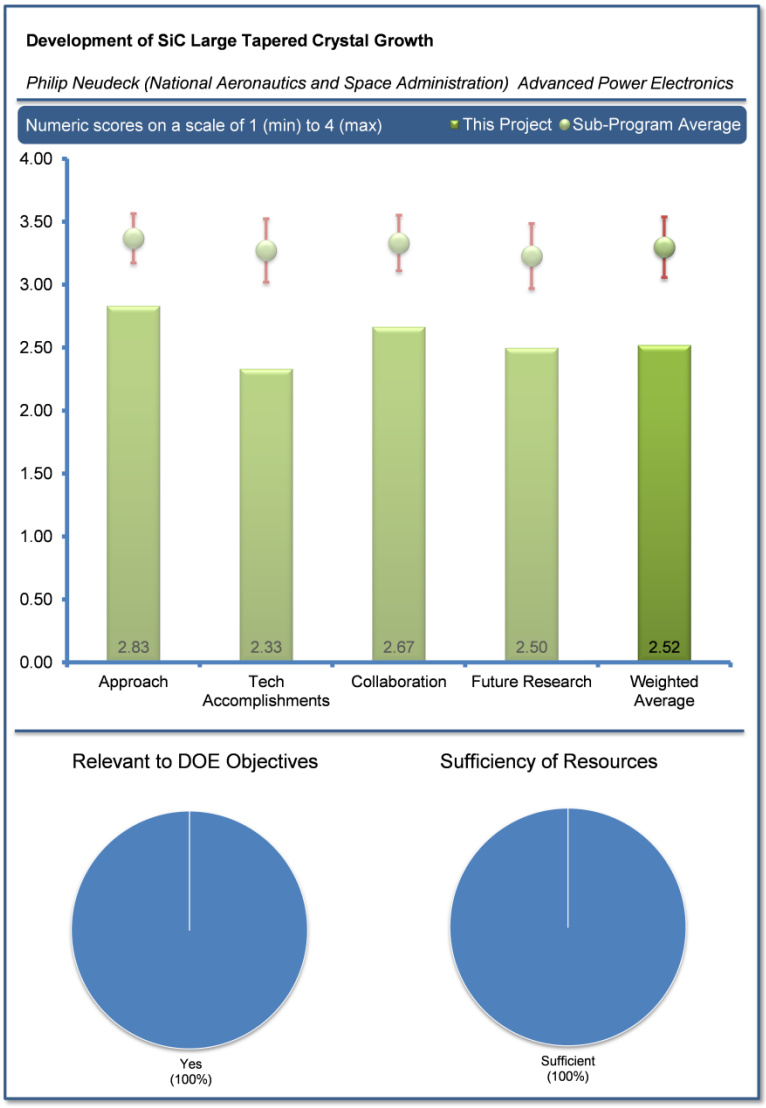
Reviewer 2:
This reviewer noted that if developed, the technology helps reduce electric-drivetrain costs and helps improve reliability of electric-drivetrain. This would result in adoption of electrified vehicle platforms, which directly and indirectly shall reduce consumption of petroleum fuel for transportation applications.

Reviewer 3:
This reviewer commented that this task was relevant to the stated DOE objective of petroleum displacement as it is has the potential to enhance the process of providing reliable and cost-effective high temperature power modules which would enable smaller, lighter, more efficient traction systems.

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

Reviewer 1:
This reviewer stated that the resources have been sufficient for the project to date and the progress has been as planned.

Development of SiC Large Tapered Crystal Growth: Philip Neudeck (National Aeronautics and Space Administration) - ape027



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 stated that the project had encountered barriers.

Reviewer 2:

The reviewer indicated that the approach to improve the quality and reduce the cost of SiC was innovative.

Reviewer 3:

The reviewer explained that the goal of this project was very aggressive with very tough challenges to be overcome at the basic science level. Not being a device physicist, the reviewer stated that the researcher's approach seemed to be reasonable and logically-organized. The reviewer, however, noted that the project suffers from a very large technical challenge to overcome, especially when faced with issues that required a significant loss of time to implement corrective actions.

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 toward DOE goals.

Reviewer 1:

The reviewer reported that while the goals were not met per the original plan, significant progress had been made. The reviewer noted the addition of the thermal imaging within the chamber is outstanding and should allow a deeper understanding of the process. The reviewer agreed that the safety upgrades, while time consuming, were necessary and would provide a piece of mind during future efforts. The reviewer also remarked that progress towards understanding what is happening during the growth process was made, and added that alternative methods had been identified but the decision factors to implement these methods were not identified. In summary this reviewer believed that this project is making good progress based on the length of the project and the issues seen to date.

Reviewer 2:

The reviewer voiced that, as this is a high-risk R&D project, it is not surprising to find many technical challenges that cannot be solved in the project.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer affirmed that the collaboration team members appeared to be the correct ones, but suggested that perhaps it might be useful to seek input from commercial crystal vendors using similar processes. The reviewer was not sure how the potential lack of funding may impact this program.

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

Reviewer 1:
The reviewer stated that the project funding was complete.

Reviewer 2:
The reviewer expressed that the proposed future work aligned very well with the current progress and stated goals of this project. The next steps are a logical progression for continued development to take place. The proposed future work included a primary path as well as a back-up plan in case the primary did not provide the desired results – good planning. The reviewer remarked that there was good potential here if the National Aeronautics and Space Administration continued to provide support.

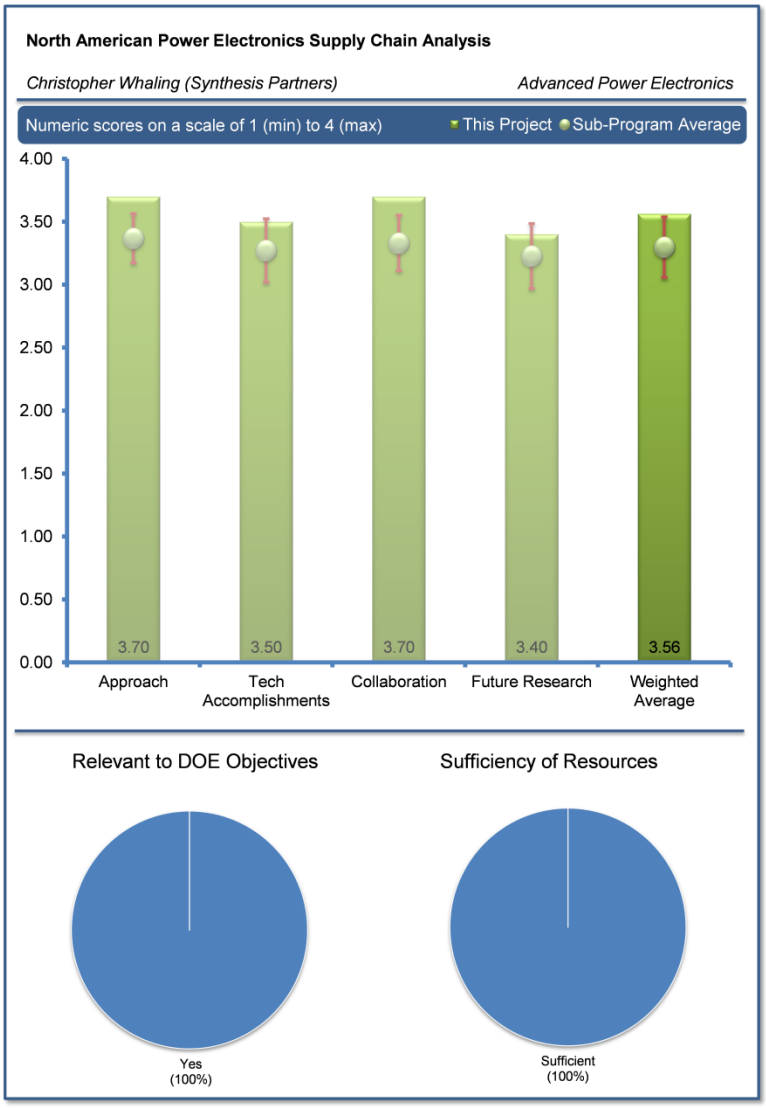
Question 5: Does this project support the overall DOE objectives of petroleum displacement? Why or why not?

Reviewer 1:
The reviewer agreed that this task was relevant to the stated DOE objective of petroleum displacement as it addresses the basic component required to produce SiC devices at a reasonable cost. The reviewer explained that having a large defect-free crystal at a low price will directly result in a more cost-competitive SiC switch.

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 had been sufficient for the project to date, for the progress had been reasonable even with the setbacks due to safety issues. The reviewer suggested that additional resources may be required to make up for the lost time.

North American Power Electronics Supply Chain Analysis: Christopher Whaling (Synthesis Partners) - ape032



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 stated that the approach looked excellent for the application.

Reviewer 2:

The reviewer confirmed that the approach to the work was very solid considering the widely dynamic and constantly changing environment in which this work was being pursued.

Reviewer 3:

The reviewer pointed out that an interaction between all players was essential for all to achieve their individual goals.

Reviewer 4:

The reviewer agreed that using interviews with suppliers and OEMs and information from publications and analyzing that information to provide recommendations was a good approach.

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 toward DOE goals.

Reviewer 1:

The reviewer liked what was discussed, but noted that progress was not covered in much detail.

Reviewer 2:

The reviewer affirmed that a good amount of results were reported. The reviewer praised that the need to, and ability to, perform the networking and relationship building is non-trivial and difficult. So, overall good work in this area.

Reviewer 3:

The reviewer commented that it was essential to be able understand and facilitate information exchange and overcome impediments in developing and maintaining an industry.

Reviewer 4:

The reviewer said that the FY 2014 project presentation should contain some recent survey conclusions.

Reviewer 5:
The reviewer noted that progress looks encouraging regarding the Interim Report topic of identifying the supply base (to collect views and interviews). The reviewer asked whether the pie chart on the North American organizations could be further broken down by Tier and potential products (e.g., motors, inverters etc.),and then be broken down again into finer detail of components by products. The reviewer also inquired about power electronics companies that are not automotive suppliers who may have a technology for automotive power electronics, whether they are one of the lower Tier suppliers, and if they are included in the analysis.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer indicated the collaboration looked great; this was a fundamentally collaborative project, and looked like this was being done well.

Reviewer 2:
The reviewer confirmed that the collaboration is excellent. This reviewer described that the number of contacts needed, the amount of information extracted, and the organization of the presentation material seemed to be the highlight of this work.

Reviewer 3:
The reviewer commented that collaboration required an understanding on both sides of the table; this means further cooperation is essential.

Reviewer 4:
The reviewer highlighted that this project had participation with numerous partners and institutions.

Reviewer 5:
The reviewer voiced that it appeared that the researchers are collecting information from many sources from the automotive supply base.

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 work is a continuation of the ongoing work.

Reviewer 2:
The reviewer requested the researchers and DOE to please continue this work. The reviewer explained that more challenges lay ahead in the area of gathering material in the intellectual property intensive space of WBG development. The reviewer added that this work was highly confidential and intensely competitive, both technically and commercially.

Reviewer 3:
The reviewer indicated that in order for the U.S. to take advantage of the power of its people, cooperation is essential. This implies that collaboration between two complimentary groups results in a significant ability to solve problems and identify new processes, while any animosity or perceived threat can be disastrous.

Reviewer 4:
The reviewer described that it appeared that the main proposed future work was for the completion of the project.

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

Reviewer 1:
The reviewer noted that reducing costs of EDVs will reduce petroleum displacement.

Reviewer 2:
The reviewer agreed that the work was very relevant and badly needed. The U.S. industry and technical presence is the area where the DOE has placed priority; therefore, this work was very relevant.

Reviewer 3:
The reviewer commented that cooperation is essential.

Reviewer 4:
The reviewer agreed that this project was very relevant to EVs, and that the project's conclusions would help to determine where additional focus was required.

Reviewer 5:
The reviewer explained that improving the supply base offered more choices for lower cost power electronics to enable EDV adoption.

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

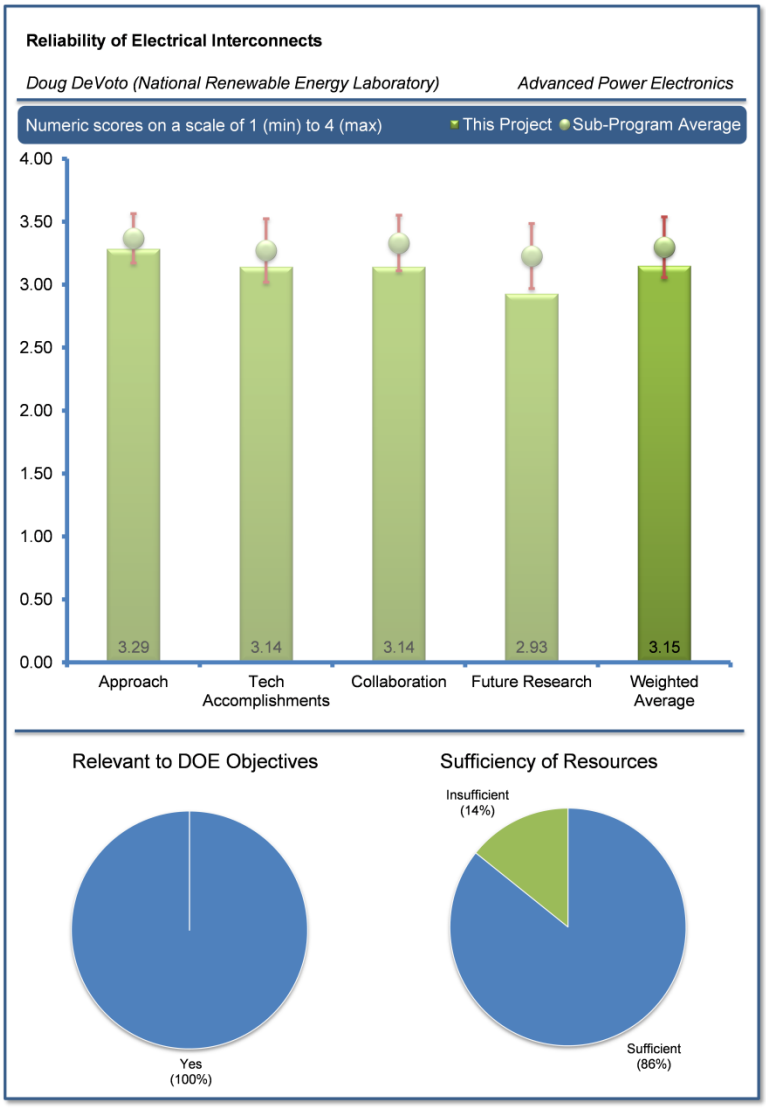
Reviewer 1:
The reviewer commented that this was not discussed in detail, but the level mentioned in the introduction seemed reasonable.

Reviewer 2:
The reviewer indicated the resources were okay.

Reviewer 3:
The reviewer agreed that the resources appeared sufficient for today's work and the presentation's scope.

Reviewer 4:
The reviewer stated that the resources were sufficient and that it appeared the results were progressing.

Reliability of Electrical Interconnects: Doug DeVoto (National Renewable Energy Laboratory) - ape036



Reviewer Sample Size

A total of seven reviewers evaluated this project.

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

Reviewer 1:

The reviewer stated that the approach was very practical.

Reviewer 2:

The reviewer commented that the work conducted was comprehensive and methodical and addressed all aspects of electrical interconnects.

Reviewer 3:

The reviewer agreed that the researchers' technical approach to replace wire bonds in power semiconductor devices by ribbons was appropriate, but mentioned that the cost and benefit analysis could have been clearer. The reviewer also noted that accelerated testing and evaluation after accelerated testing was appropriate and that the project team had devoted the desired time and resources to this effort.

Reviewer 4:

The reviewer reported that this project was generating knowledge regarding the Physics of Failure of ribbon bonded power devices; this was absolutely required to ensure that the EV market gets reliable, high-performing devices. The reviewer indicated that the planned approach, as presented, was well-thought out and appropriate for the task at hand. The reviewer agreed that the sample size and test patterns should provide adequate data to complete the task and that the overall project schedule was credible.

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 toward DOE goals.

Reviewer 1:

The reviewer acknowledged that there had been encouraging progress to date.

Reviewer 2:

The reviewer said that it would seem that the results of the work could be used to identify several "preferred or best designs" for power module interconnects. The reviewer, however, thought it would be useful to have results from extended testing of a larger sample size for the "preferred or best designs" in order to establish life and reliability.

Reviewer 3:
The reviewer reported that the project tasks were on track and that most of the tests were complete. The reviewer also agreed that reducing the number of tests needed to verify ribbon reliability was a great idea.

Reviewer 4:
The reviewer noted that this project was progressing nicely and that test data was being gathered that indicated the failure modes as a function of stress and cycles. The reviewer asserted that the development of the deformation patterns was a good addition. The project evaluator asked whether there was a significant increase in the bond time as a result of using a pattern versus a spot connection. The reviewer commended that the layout of the test samples was very good work – getting a reasonable number of samples of each wire pattern on a single sample was great. The reviewer asked whether the researchers had noticed any variability between the samples. This reviewer also asked how the researchers intend to do power cycling – on each "circuit" on each sample board – and how the researchers will get the power to the circuit. The reviewer did not see any connection areas on the sample board photos.

Reviewer 5:
The reviewer suggested that it would be better to adopt some industrial test standard for the reliability evaluation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer offered that the collaboration team members appeared to be an appropriate mix of industry experts and NREL experts. The reviewer thought it would be beneficial to enlist an outside person to review the final models/data either from industry, academia, or another national laboratory.

Reviewer 2:
The reviewer suggested that it would be useful to have inverter manufacturers as collaborators on this project.

Reviewer 3:
The reviewer pointed out that the NREL PI was collaborating with appropriate partners such as Curamik, Kulicke, and Soffa. The reviewer, however, commented that industrial partners, such as power device manufacturers, were missing from the project team.

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

Reviewer 1:
The reviewer agreed that the proposed future work addressed the challenges identified during the progress to date. The reviewer emphasized that completing the testing was high on the list and that providing a summary to the industry would be important. The reviewer suggested that the task of validating the lifetime estimation models needed to have more definition at this time. The reviewer asked who would be creating these models and what the validation would involve. The reviewer also questioned whether it could be done in the time left for this project.

Reviewer 2:
The reviewer reported that the validation of lifetime estimation model was identified as one of future research areas in the project. The reviewer recommended that a lifetime estimation model needed to be properly developed, test verified, and improved. The reviewer added that this model should also be extended to estimate the life of various thermal, mechanical and electrical interfaces in power devices using ribbon bonds.

Reviewer 3:
The reviewer commented that the proposed future work did not seem to address overcoming the remaining challenges and barriers of the project (i.e., wisely choose key experiments and ribbon bonding geometries for credible reliability prediction and validation). The reviewer recommended reviewing the research paper cited below for developing a plan to address the remaining challenges. The

reviewer stated that this paper reported a methodology to assess reliability accurately with an eigenvector sampling technique, which requires only 2N+1 analysis (where N is the number of random variables).

Paper citation: Youn, Xi, and Wang, 2008; Eigenvector dimension reduction (EDR) method for sensitivity-free probability analysis, Structural and Multidisciplinary Optimization.

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

Reviewer 1:
The reviewer agreed that this work appeared to be consistent with DOE objectives.

Reviewer 2:
The reviewer commented that this better bonding could improve WBG reliability.

Reviewer 3:
The reviewer stated that improved low costs and reliable power devices in electric drive system shall accelerate adoption of electric powertrain for traction application resulting in reductions in petroleum fuels.

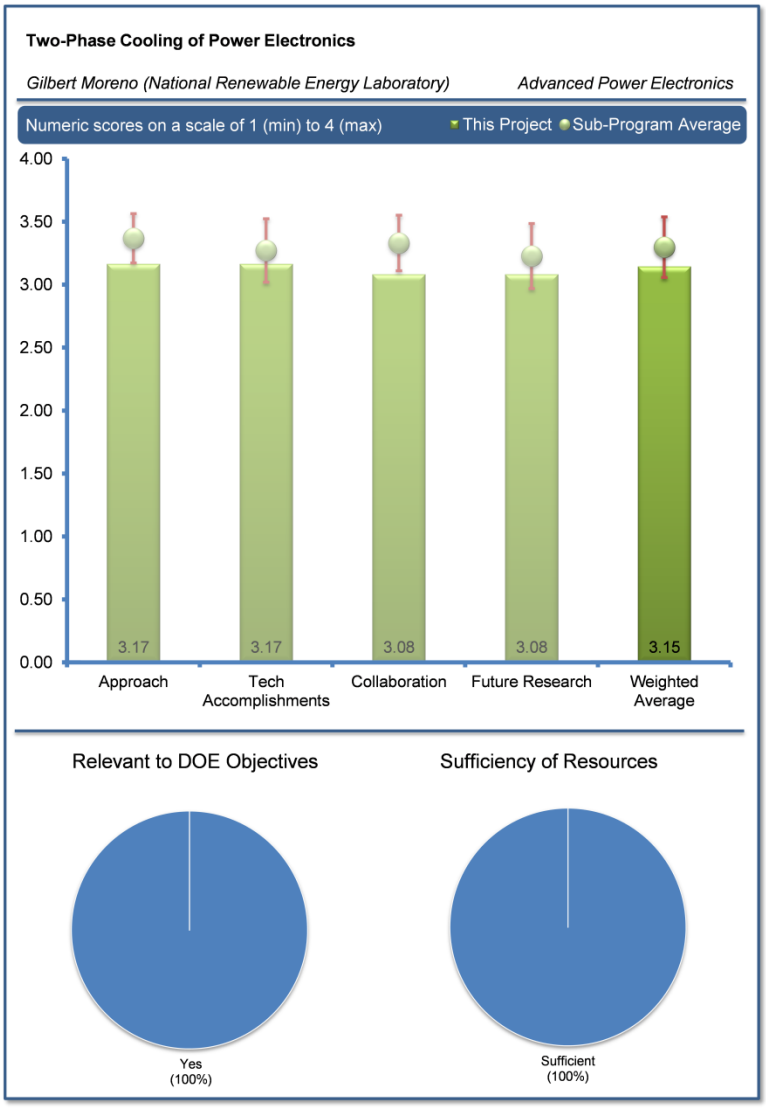
Reviewer 4:
The reviewer agreed that this task was relevant to the stated DOE objective of petroleum displacement, as it was addressing the processes required to manufacture a reliable and cost-competitive power module for the EV traction industry.

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

Reviewer 1:
The reviewer stated that the resources had been sufficient for the project to date as the progress had been carried out as planned.

Reviewer 2:
The reviewer asserted that the NREL PI should have access to at least one manufacturer of power device both in discrete and modular packages. The reviewer explained that this could have made developed technical know-how more relevant and useful due to the availability of real-world applications.

Two-Phase Cooling of Power Electronics: Gilbert Moreno (National Renewable Energy Laboratory) - ape037



Reviewer Sample Size

A total of six reviewers evaluated this project.

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

Reviewer 1:

The reviewer suggested that it would be useful to develop a cost for the two-phase cooling approach and benchmark it against a water-ethylene glycol-based approach and a heat pipe approach.

Reviewer 2:

The reviewer agreed that the technical approach taken in the project had the desired pathway for technology development and demonstration. This reviewer explained that the project had started with fundamental research progressing to inverter scale demonstration by deploying phase change thermal management technique for power devices and modules.

Reviewer 3:

The reviewer stated that the overall goals of this project were pertinent to DOE goals. The reviewer explained that the potential for this cooling approach to be successful is very good and this approach should identify the benefits and alleviate some of the concerns. The reviewer commented that the approach shown on Slide 5 (identify the fundamentals, develop at a small level, and then demonstrate at the final power) is excellent. The reviewer noted that the concern was to ensure that the final development also include the complete cooling system including the heat exchanger located in a reasonable position for use in a vehicle. The reviewer praised that the continued evaluation of alternative coolants, plus additional uses of the heat exchanger, were all good.

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 toward DOE goals.

Reviewer 1:

The reviewer stated that achieving a heat transfer rate up to 200,000 W/m2-K, while requiring only 250 ml of phase change material, was commendable. The reviewer suggested that reducing thermal resistance by 65% could attract applications from industry where two-phase cooling could be quite beneficial. The reviewer concluded that the project's tasks were on track to be completed. The reviewer reported that the investigator had demonstrated that the developed technique could heat sink up to 3.5 kW of power loss, and if adopted in application, this level of heat-sinking was quite appropriate for the majority of automotive power electronics systems rated up to 100 kW maximum power. The reviewer concluded that if this two-phase cooling technique were deployed in WBG power electronics, it could be useful for inverters for trucks and delivery vehicles with up to a 500 kW power rating.

Reviewer 2:
The reviewer stated that the project represented excellent work and that the sample proof-of-concept system test results were impressive. The reviewer agreed that using ceramic heaters of an appropriate size for today's modules was good, but asked whether the researchers had considered future devices which may be significantly smaller and thus have a smaller footprint with increased heat flux. The reviewer believed that the estimate of 3.5 kW was realistic, but pointed out that it was higher than the 2.7 kW used by the Air-Cooling Team.

The reviewer highlighted that the improvements in the fluids used as well as the enhancements to the tube design were very impressive. The reviewer also thought that including the condenser investigations was encouraging, but asked whether the researchers had met with automotive condenser suppliers regarding alternative designs. The reviewer also asked whether the researchers had considered a liquid-to-liquid heat exchanger since the vehicle may have already had a coolant available for this purpose.

The project evaluator indicated that the progress to date has been related to the cooling system, since that is the point of this project, but asked whether the researchers have considered the impact on the rest of the inverter design. The reviewer also inquired about how this cooling method would change today's inverter designs. If the condenser is still required to be higher than the condenser, the reviewer wanted to know what this would do to the interior structure of the inverter (e.g., connector locations, mounting, and volume requirements). The reviewer suggested that this should be a subject of discussion with the research team's industry collaborators, or perhaps the subject of an Electrical and Electronics Technical Team meeting.

Reviewer 3:
The reviewer commented that the work addresses all the major issues related to the design and performance of a two-phase cooling approach. The reviewer said that, assuming the performance and cost of the approach, the progress was acceptable. This person also suggested that there was a need to address the impact of a two-phase cooling approach on the life and reliability of the power device being cooled.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer indicated that the collaboration among team members was very good, and that it was encouraging to see the team reaching out to OEMs and Tier 1 supplier companies regarding challenges/issues with two-phase cooling. The reviewer encouraged to continue this collaboration.

Reviewer 2:
The reviewer proposed that it would be useful to include a vehicle manufacturer collaborator, regarding the under-the-hood integration of a two-phase cooled inverter/converter system.

Reviewer 3:
The reviewer recognized that the PI had developed a good team that consisted of industrial partners for part and material supply and universities; however, the team lacks an end-user of developed technology and technical know-how.

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

Reviewer 1:
The reviewer said that the PI had identified future research tasks and plans to work with Delphi.

Reviewer 2:
The reviewer agreed that the plan for future work was very logical, well thought out, and goals-oriented. This person stated that demonstrating this cooling approach using actual power modules should be very beneficial and would also provide a sense of relevancy to the project. The reviewer emphasized that the data from the planned testing would also be a valuable aid in getting an industry partner to assist with this project.

Reviewer 3:
The reviewer stated that the future work included bonding a Delphi power module to the advanced evaporator using a thermoplastic, but the reviewer asked why the researchers were not using a solder interface.

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

Reviewer 1:
The reviewer suggested that if this project could resolve cooling issues, it could make EVs more efficient.

Reviewer 2:
The reviewer explained that reducing inverter size and improving power density shall eventually reduce the costs of power electronics, resulting in adoption of electric powertrain in automotive traction applications. Thus, this should directly and indirectly reduce consumption of petroleum fuel.

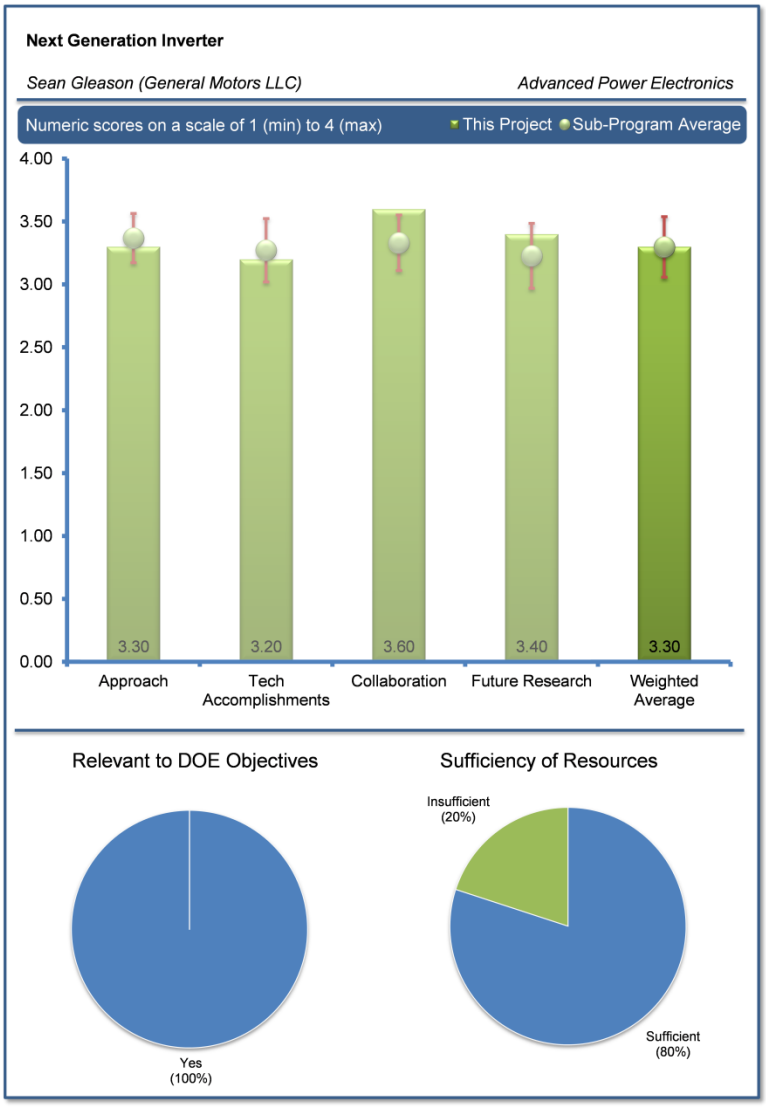
Reviewer 3:
The reviewer confirmed that this task was relevant to the stated DOE objective of petroleum displacement, as it was providing an alternate cooling method that may prove to be more cost-effective in some vehicle implementations.

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

Reviewer 1:
The reviewer commented that the resources had been sufficient for the project to date as the progress had been carried out as planned.

Reviewer 2:
The reviewer suggested that the PI should work with industry partners and find a real-world example that could adopt the developed technology.

Next Generation Inverter: Sean Gleason (General Motors LLC) - ape040



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 Sample Size

A total of five reviewers evaluated this project.

Reviewer 1:

The reviewer commented that the approach was sound and well-grounded in basic objectives.

Reviewer 2:

The reviewer explained that the project is to help Tier 1, 2, and 3 companies to co-develop technology for lower cost and increases performance is essential in today's international market.

Reviewer 3:

The reviewer said that the use of production processes in the manufacture of prototypes was an excellent approach.

Reviewer 4:

The reviewer applauded that the project has a great technical approach. The reviewer explained that the project's targets were to develop a supply chain for inverter parts and inverters, themselves, that are targeted to be scalable and modular; therefore it meets DOE's objectives for modular and scalable design of the inverter resulting in multi-platform applications to realize 100,000 inverters per year manufacturing using global supply chain and manufacturing facilities. The reviewer pointed out that the project report had a missing cost analysis and it was highly doubtful that cost targets (e.g., a real possibility of 3.3$/kW power electronics) were on track.

Reviewer 5:

The reviewer stated that overall, the project seemed interesting, but the details were not defined and it was not clear how this effort integrated with other related efforts within the DOE portfolio.

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 toward DOE goals.

Reviewer 1:

The reviewer stated the importance for components to be made from a common manufacturing process in order to lower cost with ability to produce a superior product at the lower cost.

Reviewer 2:

The reviewer reported that five inverter units were built as per project report and the gate drive circuitry was tested. The reviewer said that the device-level work seemed like it was completed. The reviewer explained that the investigator stated in the project report that no

design issues were found, however, it was hard to state conclusively that inverter design has no issues without extensive testing of inverter under loaded conditions. Overall, the reviewer agreed that the technical progress on the project seemed to be on track.

Reviewer 3:
The reviewer remarked that the progress was described as good, but this was not really demonstrated. The reviewer cautioned that, given the amount of expenditure so far, it seemed that the tangible results were limited.

Reviewer 4:
The reviewer stated that the technical goal statements and progress to these statements were intelligently-presented. However, the reviewer commented that there were fewer details than desired on the actual technical milestones. The reviewer wondered what power levels (voltages and currents) were tested and what conditions the inverters were run and tested at. The reviewer also specified that the technical objective of cost reduction, while stated as a major goal in the program now more than halfway completed (FY 2011-2016 program, with this the FY 2014 update), was not elaborated upon. The reviewer stated that it would be beneficial to know where the cost goals have been achieved, and where additional cost challenges existed. The reviewer was encouraged that GM had prototyped a power inverter product in-house at a GM facility. The project evaluator asked whether it had been tested in a GM vehicle yet, and if so, this would have been a very nice point on which to elaborate. If it had been tested, then the reviewer affirmed that this would be excellent; if not, the reviewer asked where the barriers existed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that the informal communication with other OEMs was positive.

Reviewer 2:
The reviewer observed that collaboration and coordination appeared to be both wide and deep. This seems to be the case at both the industry and also national laboratories' levels. The reviewer acknowledged that this seems to be a highlight of the work and seems prudent to continue.

Reviewer 3:
The reviewer described that the researchers demonstrated that prototype builds of common components lowered device cost, as well as improved reliability and availability.

Reviewer 4:
The reviewer praised that this project had a capable team consisting of partners from supply chain for all vital parts and components of inverter. The reviewer also recognized that the investigator was collaborating with DOE laboratories.

Reviewer 5:
The reviewer indicated that this was not discussed in the presentation, but was in the PowerPoint slide deck. The reviewer mentioned that it would have been good to discuss this more.

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

Reviewer 1:
The reviewer agreed that the future proposed work and goals seemed appropriate and well-focused, based on the program scope and objectives.

Reviewer 2:
The reviewer commented that the future plans were not discussed in detail, but the final goal seemed to be clear and responsive.

Reviewer 3:
The reviewer pointed out that common product design did not mean that there was no competition; rather it resulted in each side making a better more reliable product.

Reviewer 4:
The reviewer recommended that two units from first batch of prototypes need to be thoroughly tested under all operating conditions before the design is finalized for early build.

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

Reviewer 1:
The reviewer reported that reducing the cost and increasing market share for EDVs would be valuable in reducing petroleum use.

Reviewer 2:
The reviewer agreed that the work was consistent with the stated DOE objectives.

Reviewer 3:
The reviewer stated that the project is very relevant to meeting DOE's goal, as GM is the world's largest automotive manufacturer. The reviewer mentioned looking forward to next year's updated presentation.

Reviewer 4:
The reviewer confirmed that the ability to produce new high-performance devices with higher reliability and utility would help everyone, including the automotive industry as well as higher performance car users.

Reviewer 5:
The reviewer commented that DOE objectives could be far better supported if this project meets the power electronics cost targets of $3.3/kW.

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

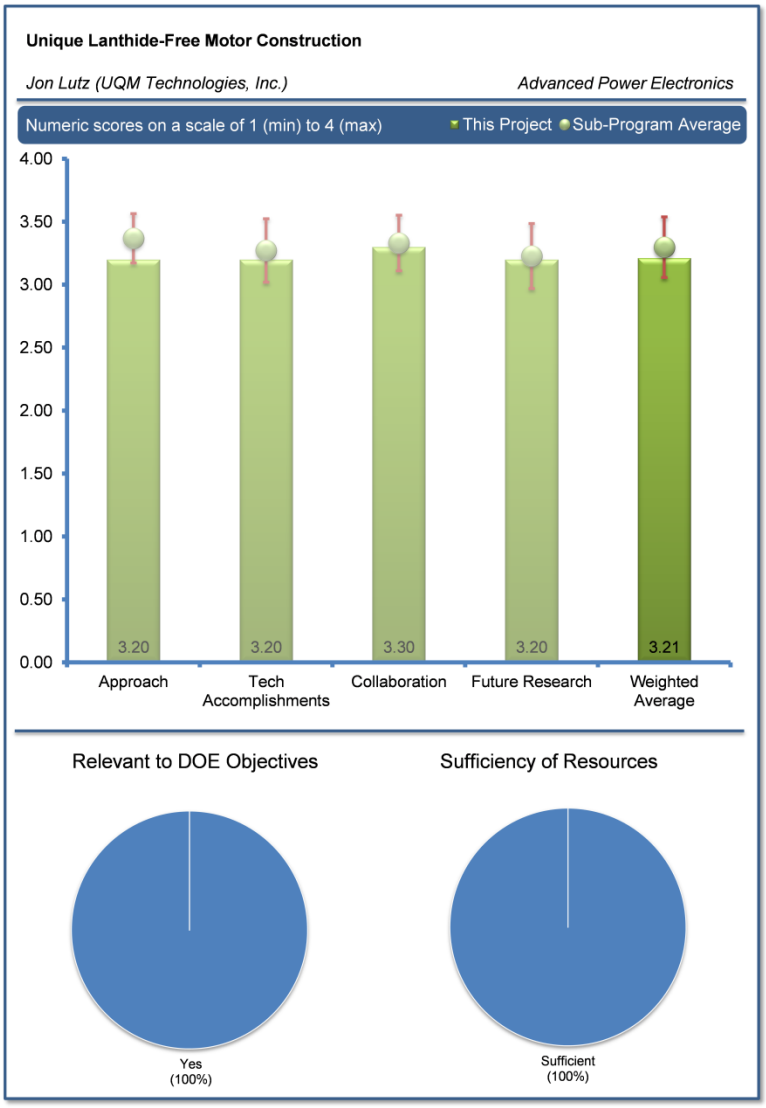
Reviewer 1:
The reviewer indicated that the resources seemed sufficient. The reviewer explained that GM had expansive resources globally, and was well-networked to pursue nearly any automotive objective from virtually any perspective. The reviewer remarked that it would be interesting to see how GM focused these resources to continue work on these important program objectives.

Reviewer 2:
The reviewer said that the resources were hard to judge, but in the present environment, assistance and cooperation could be beneficial in developing a product advance.

Reviewer 3:
The reviewer stated that access to a vehicle platform for inverter's deployment is desired. This reviewer recommended that the PI identify at least one vehicle platform for inverter application and to put the name of that vehicle in the FY 2015 project report submitted for the DOE-Annual Merit Review. The reviewer commented that merely saying that the inverter could be useful for multiple GM vehicle platforms is not enough.

Reviewer 4:
The reviewer expressed that this was not discussed in detail. The reviewer added that the spending seemed high, but these programs were complex at the OEM level.

Unique Lanthide-Free Motor Construction: Jon Lutz (UQM Technologies, Inc.) - ape044



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 Sample Size

A total of five reviewers evaluated this project.

Reviewer 1:

The reviewer stated that the approach seemed to be solid and well-experienced. The reviewer looked forward to the POC 1 results next year.

Reviewer 2:

The reviewer agreed with the logical approach to develop the AlNiCo motor (i.e., decrease the slope of the PM load line by using a long magnetic PM path, and use a high pole count to minimize demagnetizing armature reaction magnitude). The reviewer also agreed that it made sense to use a direct current (DC)-DC converter to compensate for the low constant power speed range of surface PM motor, provided this was within the scope of the original project intent from DOE. The reviewer asserted that the parallel research to increase coercivity of AlNiCo was also a good approach, as it was very challenging to meet DOE specifications with current PM material grades.

Reviewer 3:

The reviewer commented that this seemed to be a technically very well-managed project. The reviewer acknowledged the success in reaching the DOE targets also depended on the performance of the AlNiCo material to be developed by Ames. This person proposed that a design with a higher permeance coefficient and low armature reaction field was necessary when using an AlNiCo material, even if the coercivity was doubled compared to the current state-of-the-art. Given this, the reviewer commented that the chosen configuration of the magnet texture or magnetization direction seemed to work well. The reviewer pointed out that the team's responses to reviewer's previous comments were clear, including the information on the DOE approval on a lower rotational speeds level for an increased torque. The reviewer agreed that potting of the end windings seemed to have been a good choice, while the recommended oil-cooling of end windings may be problematic at 10,000 revolutions per minute (rpm).

Reviewer 4:

The reviewer summarized that the project was developing an AlNiCo-based design with a unique magnetic circuit (i.e., high permeance coefficient >> 3) to overcome the low coercivity of the magnets. The reviewer explained that since the motor was not capable of field-weakening, an integrated boost converter was required in the inverter to permit a variable DC bus voltage. Currents resulting from a stator winding or inverter fault may result in demagnetization. The motor was only designed for a 65-70°C inlet coolant temperature. The reviewer cautioned that the fiberglass magnet retention strategy had not been validated at high speeds yet, and asked whether it was possible to develop a model to predict the maximum speed achievable using the magnet retention strategy.

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 toward DOE goals.

Reviewer 1:
The reviewer commented that the technical accomplishments had been good, given the fact that only current AlNiCo magnets had been available, versus higher coercivity material magnets. However, the reviewer commented that it looked like the basic thermal design of the motor was not intended to meet the original DOE requirement of 105°C inlet coolant temperature (as far as the reviewer knew, this was the requirement shown in General Electric's (GE) presentation number ape045). The reviewer pointed out that the UQM Annual Merit Review presentation stated that the design goal was a 60-65°C inlet coolant. The reviewer added that the researchers had done a good job navigating around the need for a PM "keeper" for the rotor, and the difficulties that posed in assembly.

Reviewer 2:
The reviewer indicated the researchers were waiting on results from POC 1 and 2, but nothing negative had been disclosed.

Reviewer 3:
The reviewer stated that the work seemed to be on schedule.

Reviewer 4:
The reviewer suggested including the breakdown of losses and motor efficiency into the presentation Also, it appeared to the reviewer that the no-load losses were very high. The reviewer inquired about how the no-load losses compared to the no-load losses of surface PM and internal PM machine, and what the implications were of the no-load losses for practical applications. The reviewer suggested that a Fast Fourier Transform analysis of the back EMF voltage was needed to assess the total harmonic distortion of the back EMF. The reviewer indicated that it appears that there were some harmonics of the voltage that needed to be quantified. The reviewer also inquired about the current and improved characteristics of the AlNiCo magnets and the weight and volume difference expected by using traditional and improved AlNiCo magnets. Finally, the reviewer suggested including a 2-D cross-section of the machine with clearly marked flux paths and finite element analysis (FEA) in future reports.

Reviewer 5:
The reviewer described that the thermal enhancement modeling resulted in the design with end turn potting/encapsulation, which led to an approximately 20°C reduction in maximum end turn temperature compared to the baseline design. With this, UQM would be able to stay with water ethylene glycol cooling, rather than migrating to oil-cooling. The reviewer explained that one aspect of the design was that the magnetic circuit must be maintained, which required the need for the magnet keeper any time the rotor was not installed or during overhaul and service to avoid demagnetization. The reviewer summarized that the motor had been tested to 3,000 rpm so far and that the magnet retention strategy was a higher risk aspect of the program, to be tested prior to delivery of the motor to ORNL. The reviewer asked whether it was possible to add any design features into the rotor to provide additional mechanical retention of the magnets. The reviewer summarized by saying that UQM provided great technical details of the motor design and explanation of previous-year reviewer's concerns.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that there appeared to be good coordination with NREL on motor thermal modeling. However, the reviewer stated that it was too early to expect much engagement with Ames on improved coercivity AlNiCo.

Reviewer 2:
The reviewer acknowledged that there was apparent core collaboration in this area, while respecting independent application between several of these DOE programs on this subject matter. The reviewer highlighted that this synergy is necessary to achieve the objectives in motor development.

Reviewer 3:
The reviewer recognized that the team was well coordinated and that the collaborators were the top experts for the ascribed tasks, each of which were important for the success of the project.

Reviewer 4:
The reviewer explained that this project had some collaboration including three national laboratories supporting PM development, thermal management, and motor testing. However, the reviewer cautioned, no industry or academic partners were included. The reviewer also pointed out that no publications had resulted from this effort.

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

Reviewer 1:
The reviewer stated that the second test motor had been completed, and so now with two motors available, the UQM would be increasing the strenuous testing of the design. In the event that one motor needed to be disassembled, work can continue with the second motor. The reviewer reported that further investigation and optimization of the motor cooling strategy is planned. The reviewer added a quote from the presentation stating "ultimately, UQM expects improved magnet coercivity to be a requirement prior to product release."

Reviewer 2:
The reviewer said that the future work plan seemed to address the remaining design and test goals. If, however, the DOE goal was 105°C inlet coolant temperature, then the work and test plan should reflect this.

Reviewer 3:
The reviewer reported that the team admitted that given the current design, a voltage boost inverter was required; so this should be included in the future work.

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

Reviewer 1:
The reviewer noted that the near-term problems with heavy RE material supply had been well-documented. This research focused on the development of a motor topology built around available magnets (though at least incremental improvement is likely required) without near future supply concerns.

Reviewer 2:
The reviewer agreed that improved motor efficiency helped to achieve better miles per gallon (MPG) or miles per gallon-electric (MPGe). The reviewer also mentioned that the use of non-RE PM was a good compromise in terms of not using expensive magnets and efficiency.

Reviewer 3:
The reviewer agreed that the electrical machines developed under this effort supported further vehicle electrification and hybrid-electric applications, which would result in less fuel consumption. The project evaluator also explained that less RE content would significantly reduce the cost of advanced electric machines, which contributes to increased adoption.

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

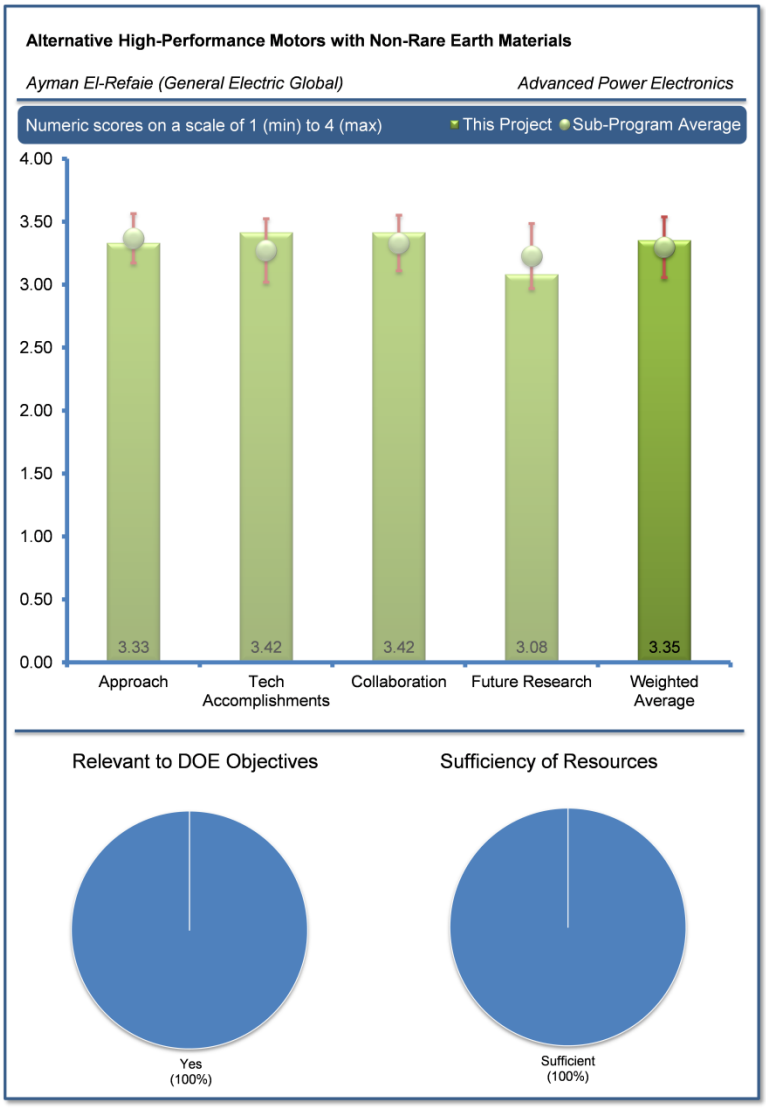
Reviewer 1:
The reviewer remarked that the resources appeared to be well-matched with the project requirements.

Reviewer 2:
The reviewer considered the project budget to be sufficient for this project.

Reviewer 3:

The reviewer stated that a lack of resources was not apparent.

Alternative High-Performance Motors with Non-Rare Earth Materials: Ayman El-Refaie (General Electric Global) - ape045



Reviewer Sample Size

A total of six reviewers evaluated this project.

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

Reviewer 1:

The reviewer remarked that this was an outstanding R&D effort, with a broad scope of technical choices. This person further remarked that with 10 variants being evaluated, this project should yield a high-value and efficient motor.

Reviewer 2:

The reviewer summarized that the project focused on high-speed designs without RE PMs, but that additional technologies were being developed under this project including novel insulation materials, controls, and thermal management approaches leveraging oil spray-cooling.

Reviewer 3:

The reviewer acknowledged that the work plan appeared to be a logical and systematic approach to meeting objectives, starting with broader categories of no heavy REs, no REs, and no magnets. The reviewer praised that the materials development being done in parallel also makes sense. However, the reviewer questioned the value of developing a slot liner that can withstand 250°C since operating at higher temperatures seemed counter to the direction of high efficiency.

Reviewer 4:

The reviewer recognized that since there were many different possible motor architectures to pursue that met the goal of reduced or eliminated RE elements, that starting the program by evaluating the possibilities was appropriate. Although, the reviewer commented that the down-selection process has proven to consume a large portion of this program. The reviewer summarized that at this point, the three candidates (i.e., no dysprosium, ferrite, and synchronous reluctance) were good choices with different pros and cons.

Reviewer 5:

The reviewer reported that although the material development group had developed a new grade of AlNiCo with higher coercivity for a $(BH)_{max}$ = 10 MGOe, the motor group had finished building a second prototype using some ferrite magnets instead. It was not clear to this reviewer if replacing the ferrite magnets with the new AlNiCo was straightforward, or if a new motor design would be needed. The reviewer however acknowledged that, regardless of the timing for the development of the high coercivity AlNiCo with respect to the schedule of this project, the reported performance was of notable importance for the research and industry communities outside of this project. The reviewer concluded by asking whether the eddy current losses in PMs were significant at the targeted 14,000 rpm rotational speed. If yes, the reviewer wanted to know how these losses are or would be addressed, especially for the magnets with the electrical conductivity of a metallic-type.

Reviewer 6:
The reviewer questioned what kind of machines are/would be used for the second and third prototypes and how the selections would be done. The reviewer suggested that more results should be shared with the reviewers to be able to assess the progress. The reviewer noted that details of the breakdown of weight, volume, and cost were needed for reviewers to understand how the program objectives were being met. The reviewer also mentioned that it would be nice to list the patents and papers published for further evaluation.

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 toward DOE goals.

Reviewer 1:
The reviewer indicated that, overall, it looked like good progress. The project evaluator reported that motors were built for two research categories, and that the results looked similar to the design predictions. The reviewer also mentioned the good progress on non-RE PM and dual-property lamination development as well.

Reviewer 2:
The reviewer highlighted that the 10 motor variants and nine patents demonstrated significant progress in this effort.

Reviewer 3:
The reviewer affirmed that the test results of the first two motors were showing promise, but suggested that it would be useful to see how these motors compared with the DOE targets (e.g., size, weight, and power profiles) rather than just the sample measurements shown in the presentation. On the materials side of the program, the reviewer agreed that the areas of work and accomplishments were useful. The reviewer stated both the use of ArKomax® 800 and "locally non-magnetic laminations" would have value in the motor designs.

Reviewer 4:
The reviewer summarized that more than 10 motor topologies seemed to have been evaluated, and that the team was designing and building three selected motor prototypes. The reviewer explained that that first motor prototype using Dy-free, Nd-Fe-B magnets seems to meet the torque and power targets at 3,000 rpm; however no specification of thermal management, weight, and volume was provided. The reviewer proposed that it would have also been useful to have concrete targets for the properties of the materials to be developed.

Reviewer 5:
The reviewer reported that the trade studies and down-selection activities had been completed and that the first two test motors had been built and were being evaluated. The reviewer also reported the following: new 250°C insulation materials are ready to be scaled-up; new directionally-oriented AlNiCo magnets with improved properties have been demonstrated; and a method to tailor the permeability across a lamination to control flux paths has been demonstrated. The reviewer highlighted that the researchers' submission of nine patent applications with others pending is very encouraging.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer indicated that the collaborators are numerous and appropriate, which is leading to good research elements.

Reviewer 2:
The reviewer described that there is apparent core collaboration in this area, while respecting independent in the application between several of these DOE programs on this subject matter. The reviewer emphasized that this synergy is necessary to achieve the objectives in motor development.

Reviewer 3:
The reviewer noted that the project had numerous motor and materials collaborators. The reviewer listed that motor collaborators included North Carolina State University, University of Akron, University of Wisconsin, NREL, ORNL, and McCleer Power, while materials collaborators included Ames Laboratory and Arnold Magnetics.

Reviewer 4:
The reviewer pointed out that there was no concrete description of the work done by the other project partners. However, the presentation, and in general, the course of the project may have been affected by the current unavailability of the PI. The reviewer supposed that with their return, the project may quickly correct its course.

Reviewer 5:
The reviewer indicated that while progress to date seemed good, more information was needed regarding coordination of the partners.

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

Reviewer 1:
The reviewer commented that the future work plan was a logical extension of the work to date, including the building of a magnet-free proof-of-principle motor and the final down-selection between the three motor types.

Reviewer 2:
The reviewer agreed that continuing to test three different motor technologies and integrating materials research was a good direction. The reviewer suggested that it would be useful to see how these technologies would be evaluated against each other and also when compared to standard RE motors, prior to the completion of testing. The project evaluator emphasized that setting the criteria in advance would help evaluate which idea(s) was the most promising for future commercialization.

Reviewer 3:
The reviewer reported that the next steps included finishing testing on the two test motors, and final motor topology selection and build. This reviewer also noted that the manufacturing processes of key materials would be scaled up. The reviewer asked whether GE would be providing a test motor to DOE/ORNL for independent verification of the advertised metrics.

Reviewer 4:
The reviewer noted that the remaining challenges and barriers were succinctly enumerated, but pointed out that there was no concrete plan on how to address them. The reviewer asked whether GE was making the prototypes and also who exactly would perform the testing. The reviewer also wondered who would scale-up the synthesis/production of the newly developed materials. The reviewer mentioned that one of the confirmed challenges is "developing the advanced materials with the required properties." However, the reviewer saw no reference to these required properties for any of the categories (i.e., soft magnetic; hard magnetic; electrically insulating). The reviewer also remarked that there was no description of the thermal management and how to address the possible mechanical challenges that resulted from a high rotational speed level operation.

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

Reviewer 1:
The reviewer commented that the project focused on meeting DOE's high performance and efficiency motor targets with zero heavy RE or zero RE content. The reviewer agreed that this was directionally correct for the goal of widespread electric vehicle use with sustainable material supply.

Reviewer 2:
The reviewer stated that the high-performance alternatives to RE motors would prevent vehicle electrification from being derailed due to potential disruption in RE supplies.

Reviewer 3:
The reviewer agreed that the electrical machines developed under this effort support further vehicle electrification and hybrid-electric applications, which would result in less fuel consumption. The reviewer added that less RE content would significantly reduce the cost of advanced electric machines, thus contributing to increased adoption.

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

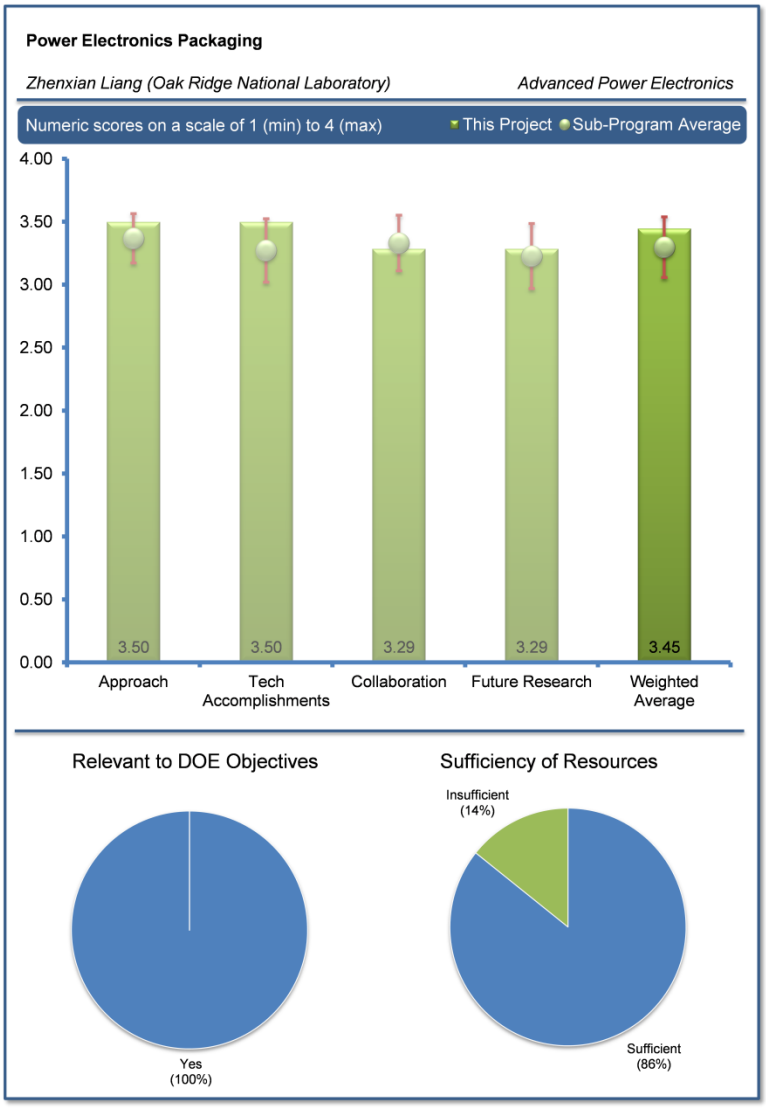
Reviewer 1:
The reviewer indicated that a team this large should be able to meet the stated goals on time.

Reviewer 2:
The reviewer noted that the resources for this program appeared to be appropriate.

Reviewer 3:
The reviewer thought that the $12 million budget was sufficient for this project.

Reviewer 4:
The reviewer said that a lack of resources was not apparent.

Power Electronics Packaging: Zhenxian Liang (Oak Ridge National Laboratory) - ape049



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 explained that automotive inverter designs need modification to meet the DOE Advanced Power Electronics and Electric Motors program target. The reviewer noted that Si power modules were being developed to meet the new requirements.

Reviewer 2:

The reviewer commented that the project looked like good work, but was unclear how this work contributed to the larger system-level goals.

Reviewer 3:

The reviewer reported that the desired approach was adopted by the investigator to develop novel packaging ideas and test verification of the developed ideas. The reviewer agreed that replacing Si semiconductor material with WBG material was a great idea. However, the reviewer reported that to use performance of WBG devices, the package should be developed with the minimum possible stray parameters for electrical, mechanical, and thermal; that was exactly what the investigator was striving to achieve through this project.

Reviewer 4:

The reviewer praised that the project addresses most of the important issues within the power module with very impressive goals. The reviewer liked the planar connection approach, but had some concerns relative to spacing (e.g., clearance spacing outside the module) and the impact of connecting to bus bars within the inverter as well as the signal interfaces. The reviewer also noted that the power module package appeared to be very compact, but that the dimensions were not provided (the assumption was based on views relative to the quarter shown in the photos). The reviewer also indicated that the drawings did not include a means for mounting the power module in the inverter. This may create problems in the final package in order to provide the required support and still meet creepage and clearance requirements. The reviewer asked if any thought had been given relative to making the connections to the gate drive circuitry such as connectors or board mounting provisions if press fit pins were used.

Reviewer 5:

The reviewer remarked that the approach to performing work was very sound and effective. The reviewer suggested that goals for which applications were being targeted would be helpful in the first part of the presentation as “Power Module Packaging” can be directed at many different applications from main inverter at high power and low frequency to accessory applications at lower power and higher frequencies.

Reviewer 6:
It was not clear to this reviewer how the double-sided power elements were assembled to create a full-size power module. The reviewer indicated that it was difficult to assess the practicality of the approach without having an understanding of the details of the design.

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 toward DOE goals.

Reviewer 1:
The reviewer observed interesting progress and looked forward to seeing the results of integration of the third-generation device into a system.

Reviewer 2:
The reviewer explained that it was commendable that the researchers were finishing the project tasks related to packaging and test evaluation of the Generations 1 and 2 SiC devices and modules for the inverter. The reviewer also noted that the PI had also developed packaging ideas for the Generation 3 devices for the inverter module. Overall this person thought the technical tasks for project seems to be on track to complete.

Reviewer 3:
The reviewer commented that the new advanced design power module for inverters, and etc. had been developed where Si-based devices replaced by SiC and GaN devices. The reviewer explained that a significant 40% cost reduction and a 60% power increase had been achieved in the new devices.

Reviewer 4:
The reviewer commended that the packaging concepts were highly integrated and highly technical. However, it was not clear to this person if wire-bonded semiconductors would be used in the most advanced package type. The reviewer explained that there was a picture on Page 5 showing a wire-bonded device, then on Page 12 die attach appeared to be direct-bonded; thus this would be a nice area to clarify. This person summarized by indicating that the overall technical accomplishments looked very promising and well-founded. The reviewer added that the researchers had done nice work.

Reviewer 5:
The reviewer suggested that the researchers needed to develop a cost assessment of the proposed third-generation package design to demonstrate that the 40% cost reduction was achieved. This person also thought that it would be useful to benchmark the third-generation package design cost against a current power module cost.

Reviewer 6:
The reviewer agreed that the packaging approach has made very good progress in terms of size reduction with excellent thermal performance, as seen in the performance charts. The reviewer commented that the electrical performance indicated some areas that needed improvement, such as noise on the output signals, but appeared to be good overall. The reviewer affirmed that the module's simulated performance showed very good switching results for this package in terms of voltage overshoot. This performance was based on a circuit attached to a copper baseplate, versus the planar package being proposed. The reviewer asked when these tests would be repeated with a more representative package. The reviewer indicated that the assembly process shown on Slide 14 showed two different jigs for the assembly of the module with the jig on the right side most closely matching what the project team thought would be the pin out of the module to support the three- phase package shown in Slide 12. The reviewer asked the researchers to explain which the correct jig was, as the reviewer was not sure that the researchers wanted to have the output exit from the same side as the high-voltage DC input to the module from a crosstalk perspective. The reviewer asked if any thought had been given to what other functions might be included in this module, such as temperature sensing of the switches and current sensing (more for fault control than control at this time). The reviewer also asked if the cooling plate properties had been modeled; specifically, the reviewer wanted to know the flow rate and pressure drop of a single plate and of the proposed full model using a 50% water/50% ethylene glycol mixture. The reviewer emphasized that this was an important parameter in the construction of the traction system, as it directly impacts the size and thus the cost of the pump. In summary, the reviewer believed that this project was making good progress based on the length of the project to date.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer affirmed that it looked like the level of collaboration was appropriate to the requirements.

Reviewer 2:
The reviewer acknowledged the excellent collaboration and coordination were incorporated. The reviewer pointed out that many key industry partners and other national laboratories were engaged appropriately.

Reviewer 3:
The reviewer stated that the achievements in the project were achieved through cooperation that will benefit industry.

Reviewer 4:
The reviewer voiced that the PI had put together an excellent team consisting of industry partners, academic experts, and partners from NREL. The reviewer suggested that the PI should find an industry partner such as an end-user of developed packaging ideas for increased power density, reduced costs, and improved performance.

Reviewer 5:
The reviewer observed that the effort would derive benefits from participation of inverter/converter manufacturer(s) and vehicle manufacturer(s) regarding system design specification and system integration into a vehicle.

Reviewer 6:
The reviewer commented that the collaboration within the DOE labs, university work, and with the device and packaging industry partners appears to be good and is providing excellent results. What the reviewer saw as missing was active participation with the eventual users of this technology – the Tier 1 and 2 suppliers and vehicle OEMs. The reviewer admitted that it may be that it was too early for their active involvement, but still believed that they should be reviewing the proposed packages to provide constructive input as to what the appropriate form factor should be for incorporation into their product, or at least have some time to determine its impact on their product.

Reviewer 7:
The reviewer indicated that Slide 15 stated that the new power module reliability would be done in collaboration with NREL in response to a comment in FY 2013; however, no such reliability analysis had been done in this year's report. In addition, this person indicated that, according to the table in Slide 6, NREL would work on thermal analysis, which implied that only reliability of the thermal performance may be conducted. The reviewer cautioned that conducting only thermal reliability analysis was not sufficient because any other reliability issues could hurt the commercialization of the technology, even though the cost and power density targets were met.

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 suggested continuing the program in order to optimize other technologies.

Reviewer 2:
The reviewer agreed that the future research appeared to be well-aimed and properly focused. The reviewer suggested that providing a very clear break out of what industry applications were being targeted for the solution (e.g., automotive inverters, automotive DC-DC applications, motor drives, industrial applications, etc.) would be a nice addition to the work. The reviewer asserted that while not a deficiency to this presentation, this would be a well-received addition to the material to help the audience better understand what industry application challenges could be addressed by this exciting work.

Reviewer 3:
The reviewer highlighted that the PI was willing to provide packaging support to the Advanced Power Electronics and Electric Motors program projects underway at various national laboratories and industries, which the reviewer found to be a commendable offer made through the project report. The reviewer also concluded that the PI had identified enough tasks to keep making the desired progress during the remaining period of FY 2014 and for all of FY 2015.

Reviewer 4:
The reviewer commented that the proposed future work aligned very well with the current progress and stated goals of the project. The reviewer explained that the next steps were a logical progression for the development to take place. This person suggested that the addition of some environmental tests, such as vibration and thermal testing to validate the model, would be helpful and would both validate the model and help identify areas that are in need of improvement. The reviewer would have also liked to see the module be subjected to some of the standard module tests, such as thermal and power cycle testing to determine its long-term performance.

Reviewer 5:
The reviewer reported that the next step appeared to be the integrated unit, but it was not clear what this would actually be used for and how this contributed to integrated systems.

Reviewer 6:
The reviewer requested that the future work include a proof-of-concept full-scale inverter/converter performance demonstration. This person also explained that the future work should address the life and reliability of the third generation package design.

Reviewer 7:
The reviewer suggested that the plan to enhance the reliability for only (or most likely) thermal performance needed better justification because any other reliability issues (e.g., electrical, mechanical, lifetime, etc.) could hurt the real application of the technology. In addition, the reviewer was concerned that the team seemed to lack expertise in reliability analysis. This person indicated that NREL probably will work on thermal analysis, rather than reliability analysis of the thermal performance, according to the table in Slide 16.

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

Reviewer 1:
The reviewer confirmed that reducing the costs of EDVs would lead to reductions in petroleum displacement.

Reviewer 2:
The reviewer applauded that the work was very relevant. The reviewer emphasized that power electronics packaging was among the key areas where future advances were needed.

Reviewer 3:
The reviewer said that the project benefits all of the involved companies.

Reviewer 4:
The reviewer affirmed that smaller packages for power inverters with reduced costs and improved performance are key enablers for the rapid deployment and adoption of HEV and EVs for transportation systems. Efforts through this project should achieve these objectives resulting in reductions in consumption of petroleum fuel.

Reviewer 5:
The reviewer agreed that this task was relevant to the stated DOE objective of petroleum displacement, as it is addressing the power module which is a significant and unique piece of the electric traction system. This person explained that the power module had a huge impact on the performance, size, mass, and reliability of the system, as well as the impact of driving the size of other components, such as the bulk capacitor.

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

Reviewer 1:
The reviewer described the project's resources as adequate.

Reviewer 2:
The reviewer stated that the resources were not discussed in details, but seemed to be adequate.

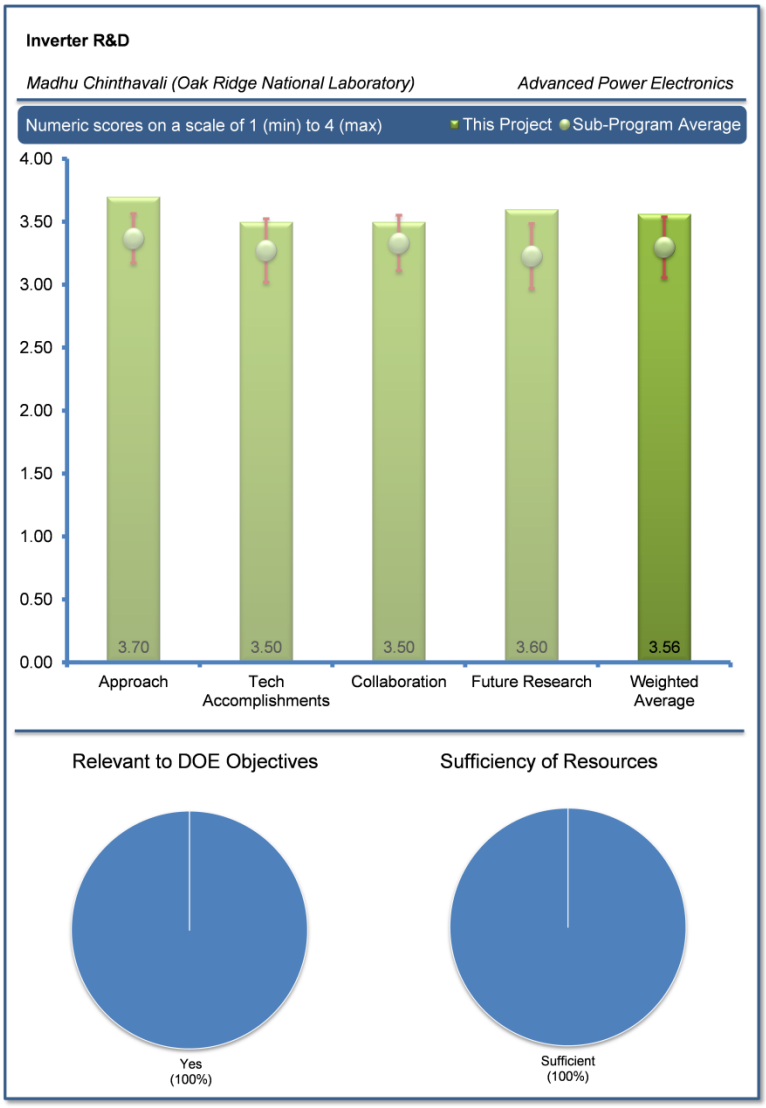
Reviewer 3:
The reviewer commented that the project resources seemed well-positioned and correctly weighted for this work.

Reviewer 4:
The reviewer stated that the resources had been sufficient for the project to date as the progress had been reasonable. The reviewer suggested that the mix of expertise may need to be changed to include testing and perhaps some input from an OEM and/or Tier 1 inverter supplier regarding how to package the module and the features required to support it.

Reviewer 5:
The reviewer recommended that the PI should find an industrial partner as an end-user of the developed technology.

Reviewer 6:
The reviewer commented that the team may have underestimated the work in reliability analysis for the packaging technology. Hence, the resources may be insufficient if reliability analysis would be seriously considered in the future work. In addition, the team would need to add a person whose expertise was in reliability engineering.

Inverter R&D: Madhu Chinthavali (Oak Ridge National Laboratory) - ape053



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 explained that it appeared that a variety of approaches, many of which have the potential for significant gains, had been attempted.

Reviewer 2:

The reviewer noted that the approach compared liquid-cooled and air-cooled technologies.

Reviewer 3:

The reviewer agreed that the approach was very sound. This person explained that much good information on supplier and component was offered, but suggested that elaborating on more specifics would be helpful to the audience.

Reviewer 4:

The reviewer recommended that differences between the other funded 55 kW WBG inverter project (APEI) and this project should be clearly cited, as this would distinguish the contribution of this project from the other projects in a strong manner.

Reviewer 5:

The reviewer confirmed that this project had adopted a great approach to reducing the overall costs of the electric drivetrain by the inverter package using lower cost and reduced size materials and parts, such as copper bus bars in the inverter assembly. The reviewer explained that reducing the parts count, without compromising inverter's functionalities and inverter performance, is quite commendable if it is achieved and deployed in real-world application. This person commended that combining circuits' functionalities to reduce the part count was quite an attractive approach. The reviewer agreed with the researchers that building a 10 kW WBG inverter using commercially-available parts was the right approach to verify the design for manufacturability. However, the reviewer asked if this inverter design could be scaled-up to operate at higher voltages to exploit the high-voltage properties of SiC devices and modules. The reviewer reinforced that this needed to be answered conclusively by the PI.

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 toward DOE goals.

Reviewer 1:

The reviewer indicated that it seemed that there were a number of promising preliminary results, and looked forward to the 55 kW results.

Reviewer 2:
The reviewer stated that there had been encouraging progress and results to date.

Reviewer 3:
The reviewer expressed that the technical accomplishments and benchmarking were excellent. The reviewer suggested that more information on cost would be a very nice addition to the material.

Reviewer 4:
The reviewer suggested that it would be beneficial to show the breakdown of weight and volume of the converter designs and total weight and volume. This should include SiC and GaN devices, gate drive board, controller board, any sensors, mechanical packaging, any AC and/or DC capacitors, any AC and/or DC inductors, heat sink, any connectors, and miscellaneous items for cables, etc. The reviewer explained that this approach would clearly show how the objectives of the weight and volume were being met in detail.

Reviewer 5:
The reviewer summarized that the power density achieved using the ORNL packaging idea was 5.88 kW/l, which is quite a bit lower than the 12.00 kW/L DOE FY 2015 targets and 13.40 W/L DOE FY 2020 targets). The reviewer requested that the PI verify if the lower right corner graph shown on Page 7 was correct. The reviewer also summarized that discrete and modular SiC devices had been characterized in laboratory testing, but had yet to be tested in an inverter setup to predict efficiency of the 10 kW SiC inverter, (air-cooled and liquid-cooled versions). The reviewer pointed out that the inverter offered 99.3% efficiency; however, determining the inverter efficiency over a load range (e.g., 10% of load to full load) is recommended. The reviewer also recommended that the PI to develop a protection scheme for the various vital inverter parts and to document how these schemes work under high dV/dt environment without any false trip of inverter operation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer voiced that this project has excellent collaborative efforts with team partners drawn from ORNL, NREL, inverter part suppliers, and WBG device manufacturers companies.

Reviewer 2:
The reviewer mentioned that the collaboration and coordination with other industry partners and institutions was nicely integrated into the presentation.

Reviewer 3:
The reviewer reported it looks like the collaboration is great, although it sounds like more collaboration on advanced capacitors could be helpful.

Reviewer 4:
The reviewer recommended that it would be nice to see a couple of universities as collaborators as well to make the team stronger.

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 scaling plans appeared to be in place, and was looking forward to the results.

Reviewer 2:
The reviewer acknowledged that eliminating the liquid-cooling should enhance the efficiency.

Reviewer 3:
The reviewer agreed that the future proposed work was well-aligned with the scope and objectives of the program.

Reviewer 4:
The reviewer praised that the investigator had commendable and challenging tasks identified to scale-up the 10 kW inverter to a 55 kW inverter design. The reviewer recommended that all attempts should be made that this scalability is achieved with minimum possible design changes in the inverter parameters and dimensions related to electrical, mechanical, and thermal, etc.

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

Reviewer 1:
The reviewer agreed that decreasing EDV costs would lead to petroleum use reductions.

Reviewer 2:
The reviewer stated that the work was consistent with DOE objectives.

Reviewer 3:
The reviewer confirmed that this work was very relevant, as it aimed to better understand the work that was progressing to solve many needed and targeted application solutions.

Reviewer 4:
The reviewer agreed the research presented was relevant to DOE because it achieved significant efficiencies of converters using SiC and GaN technology. Hence, future cars would achieve better MPG or MPGe due to the inverter efficiency increase.

Reviewer 5:
The reviewer explained that if the air-cooled 55 kW SiC inverter design was proved-out in a vehicle application, this could open new applications of the WBG power electronics deployed in the light-duty transportation vehicles. Due to the high operating efficiency and smaller size of the WBG inverter, the developed product could become an enabling technology to reduce consumption of petroleum fuels.

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

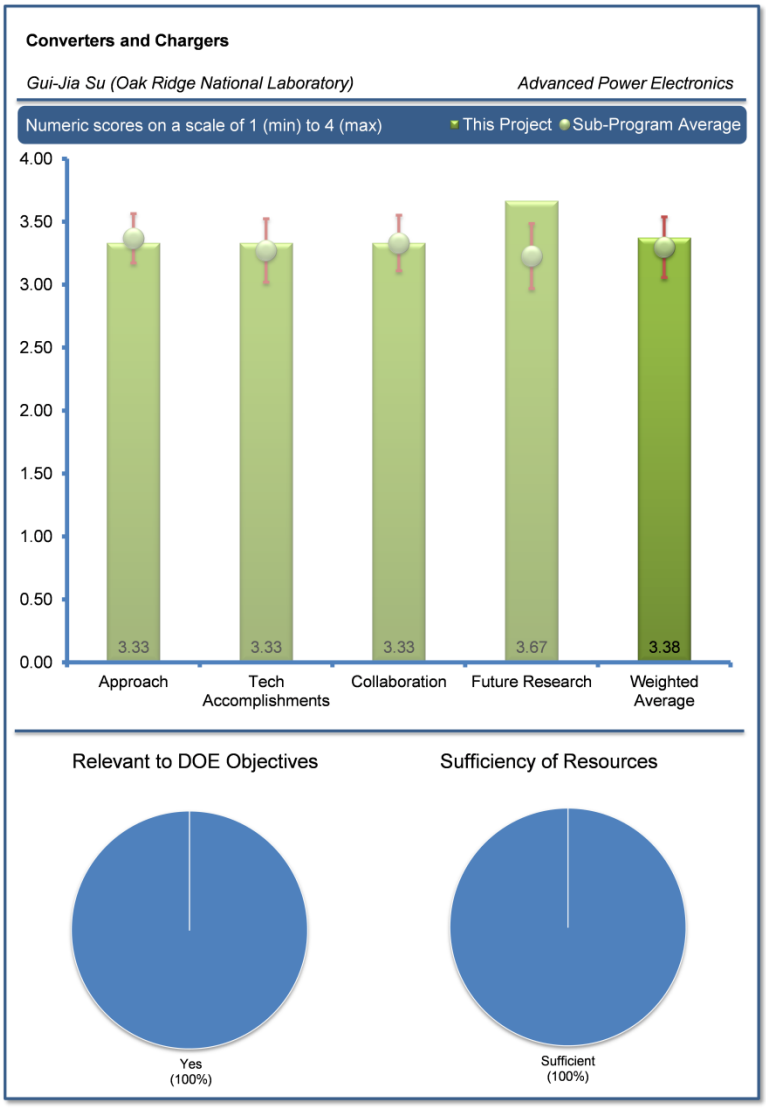
Reviewer 1:
The reviewer commended the team’s nice work and well-laid out project. The reviewer reported looking forward to seeing next year's contribution.

Reviewer 2:
The reviewer reported that the resource level was not really discussed, but there did not seem to be gaps.

Reviewer 3:
The reviewer indicated that the resources appeared to be sufficient and well-placed to achieve the program objectives. The reviewer suggested that commercial resources may be able to be included to address the areas of cost, as R&D efforts must be focused on application solutions that are cost-effective paths to production.

Reviewer 4:
This reviewer recommended that the project team should strive to work with an industrial partner who could adopt the air-cooled 55 kW SiC inverter, including providing a commercial vehicle platform for performance verification of the developed air-cooled WBG inverter.

Converters and Chargers: Gui-Jia Su (Oak Ridge National Laboratory) - ape054



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 indicated that it was a valuable approach to evaluate the possibility of reducing the cost by sharing the power stage with traction inverter and motor.

Reviewer 2:

This reviewer highlighted that the goals of this project were very aggressive and that several barriers were being addressed. One concern the reviewer had was the use of the drive motor(s) as part of the charging implementation. The reviewer asked whether all of the costs and other impacts had been documented and a plan identified to address them. This person noted that there was a cost associated with bringing the neutral point of the motor(s) out of an oil-cooled drive unit. The reviewer liked the combined charger/auxiliary power module (12 VDC APM), as this combined the two functions that needed to be operating during charging. The issue with this approach was the efficiency of the APM at very light loads (less than 250 watts or so) since this power cannot be used to charge the battery. The reviewer also explained that another potential issue that needed to be addressed was the overall vehicle safety during charging. The reviewer asked if this approach limited the leakage path back to the electric vehicle supply equipment (EVSE) while it maintained isolation of the high-voltage bus. The leakage current needed to be modeled and compared to the allowable limits. The identified designs assumed either a dual motor system or a single-motor boosted system which may not cover all implementations. There are single-motor non-boosted systems that still require a charger – could be a slight change in the location of the "boost" inverter which would impact size of the unit. The project evaluator asked what the impact was to the function in a dual-motor system that uses motors of different sizes, and thus different inductances. The reviewer also commented that no mention was made regarding the size, cost, or mounting location for the contactor, which could be significant. There are charger-only units (3.3 kW) under development that are in the 900 W/L range, so the market was also reducing size and increasing power density. The reviewer would have liked to see a standalone implementation of just the charger and APM.

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 toward DOE goals.

Reviewer 1:

This reviewer expressed that additional design details were needed to assess the feasibility of the proposed integrated on-board charger. The reviewer asked whether the required DC-inductor value and the machine winding inductance compatible with each other; this was critical to find out whether this topology was viable. The reviewer recommended that a traditional charger topology would be compared

to the proposed integrated on-board charger from the perspective of part count, weight, and volume. The reviewer also commented that it would be beneficial to show the breakdown of weight and volume of the converter designs and total weight and volume. This should include SiC and GaN device, gate drive board, controller board, any sensors, mechanical packaging, any AC or DC capacitors, any AC or DC inductors, heat sink, any connectors, and miscellaneous items for cables, and etc. This approach would show how the objectives of the weight and volume are met in detail.

Reviewer 2:

This reviewer admitted that while the reviewer was not a fan of using the inverter/motors as part of the charging system, the project had made good progress on the basic charger design. The reviewer's questions related to the impact on the system cost of using the inverter/motors but other areas are being identified such as the need for a new magnetic material capable of supporting the higher frequencies that are desired. Test data from the breadboard unit indicated that the topology was viable even in Si, and should be usable as a baseline for comparison purposes. The reviewer reported that testing of WBG devices had started with preliminary results that matched data from other sources. The reviewer asked whether the test data shown used the gate drive circuit in the presentation or another pre-existing design. The project evaluator agreed that the planar transformer design looked good, but asked what experience the researchers' vendor had with heavy copper boards at 120 amps (for APM). The reviewer also agreed that a 2.0 kW APM is a reasonable values as typical units are 1.8 kW or 2.2 kW in the reviewer's company's product portfolio. The reviewer asked if any analysis had been performed on the number of additional hours that the inverter/motor will be subjected to if used as part of the charger. The reviewer also asked what the voltage/current stress was on the bulk capacitors. The reviewer noted that these questions needed to be addressed to adequately judge the cost impact of this approach. In summary, the reviewer believed that this project is making good progress based on the length of the project to date.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

This reviewer suggested that it would be nice to add a couple of universities to the project in order to diversify the team which would strengthen the team's depth and breadth.

Reviewer 2:

This reviewer affirmed that the collaboration with device suppliers was showing results. However, only one of the three magnetic material suppliers was mentioned. What the reviewer saw as a missing piece was active participation with the eventual users of this technology – the Tier 1 and 2 suppliers and vehicle OEMs – input required to address cost, reliability, and safety impact of the design.

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

Reviewer 1:

This reviewer reported that the proposed future work aligned very well with the current progress and stated goals of the project. This person agreed that the next steps were a logical progression for the development to take place. The reviewer questioned whether addition of the 3.3 kW GaN charger, rather than going straight to the 6.6 kW charger design, was based on device availability or another reason. The design of two 6.6 kW chargers is ambitious especially if the topologies are going to be significantly different to take advantage of the device characteristics. The reviewer asked whether the PI plans to use a common design, or modify the design to take advantage of both technologies. This person stated that an apples-to-apples comparison would be very helpful once both designs were tested.

Reviewer 2:

This reviewer proposed that it would be good to test the proposed on-board charger module in the real car and EVSE (i.e., charger environments).

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

Reviewer 1:
This reviewer agreed that this task was relevant to the stated DOE objective of petroleum displacement as it is addressed the reduction in size of the charger and APM by combining them with the inverter/motor. The reviewer pointed out that this one possible implementation, but the reviewer thought that the combination of the charger and DC-DC was viable if the size was easier to package than the current use of separate units; sometimes two small units are easier to package than one slightly larger unit.

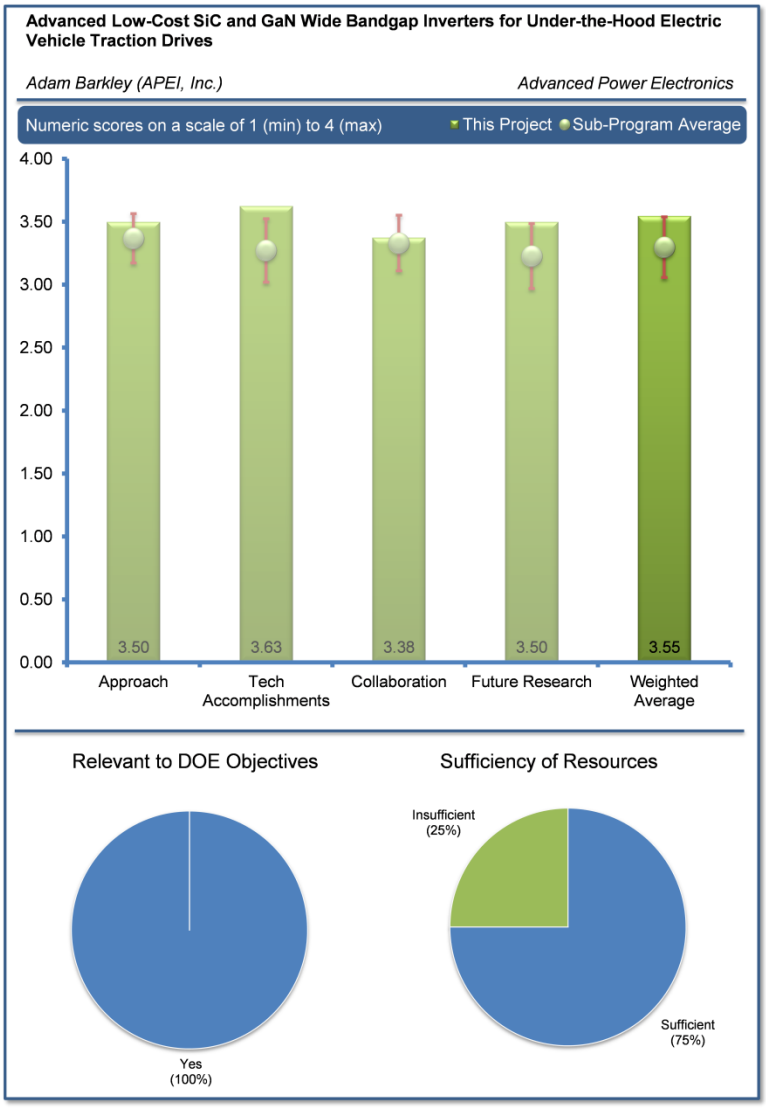
Reviewer 2:
This reviewer explained that low-cost onboard charging modules are critical devices for PHEV and EV vehicles.

Reviewer 3:
The reviewer voiced that the PI needed to add a slide to show how this objective was met. The reviewer answered yes, because the battery charger uses utility power, and it could be assumed that the charger efficiency increase indirectly contributed to petroleum displacement.

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

Reviewer 1:
This reviewer indicated that the resources had been sufficient for the project to date as the progress had been reasonable. The reviewer remarked that more use of the magnetic material suppliers would probably be required to increase the probability of success in case the nano-material did not work out. The reviewer recommended also including an OEM or system integrator to assist with some of the safety concerns with this implementation.

Advanced Low-Cost SiC and GaN Wide Bandgap Inverters for Under-the-Hood Electric Vehicle Traction Drives: Adam Barkley (APEI, Inc.) - ape058



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 agreed that comparing the two WBG technologies seemed to be very interesting. The reviewer suggested, however, that the work may have too much of a near-term focus on component selection and topology, given the somewhat speculative nature of the devices, but this would at least create a benchmark.

Reviewer 2:

This reviewer stated that the project's approach was to eliminate wire bonds.

Reviewer 3:

This reviewer stated that the approach and focus were well-articulated and clearly explained.

Reviewer 4:

This reviewer commented that a better approach could be to focus on one inverter design for research investigations followed by inverter's parts design and development and manufacturing of inverter prototypes required for design verification and design improvements. The reviewer explained that the project work and tasks on both GaN and SiC inverters could not get optimum results due to the divided efforts between the two incompatible deigns. During the FY 2014 DOE Annual Merit Review, the APEI presenter stated that the APEI team was far ahead on the SiC-based inverter and this researcher questioned this approach as SiC devices are better suited for higher voltage (greater than 1,000 VDC) inverters, rather 380 VDC nominal bus voltage inverters. Successful market penetration followed by significant capture of business segment by SiC devices is unknown for lower DC bus voltage inverters, as SiC devices at lower voltages are not competitive with the GaN devices due to cost and performance considerations and untapped capability of SiC devices (e.g., paying for capability but not using it). The reviewer noted that APEI plans to use its proprietary ASIC technology; more information would be helpful to understand the potential impact to encouraging WBG power electronics manufacturing in the United States at a large scale.

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 toward DOE goals.

Reviewer 1:

This reviewer noted that the project was still at an initial phase, but appeared to be on target.

Reviewer 2:
This reviewer stated that the technical details were well-presented.

Reviewer 3:
This reviewer praised the excellent data presentation and technical merits of different approaches that were communicated effectively. The reviewer pointed out that due to the nature of WBG technology, the differences in efficiency at light loads of WBG materials versus Si should have been elaborated upon. The reviewer indicated that the cost, weight and volume ratios were well-presented, but suggested that they could be additionally expanded upon. The reviewer remarked that this seemed to be the area of work that the audience was most interested in.

Reviewer 4:
This reviewer explained that at least four conceptual designs were depicted in the project report used for presentation during the DOE Annual Merit Review. The reviewer recommended that the investigator carry out a comparison analysis among all four concepts and share this analysis data with DOE for pros and cons of each concept. The reviewer proposed that this could become a decision analysis exercise and could have valuable information for future design revisions during the course of this project. The project evaluator asserted that it could have been quite useful for reviewers if the investigator had shared the high-level technical specifications, including results from modeling and simulation tasks completed. The reviewer recognized that the electrical and thermal characterization results from the SiC packages were commendable to show, and prove, the promise of WBG power electronics. Sharing pictures of project work underway was greatly appreciated by this reviewer.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
This reviewer noted that it seemed like the project team had a promising set of partners.

Reviewer 2:
This reviewer reported that the collaboration was well-presented. Due to the increased numbers of WBG suppliers over recent years, it seemed to the reviewer that a wider inclusion of offerings would be a nice addition to this work. The commenter understands that intellectual property protection and the competitive nature of this landscape made this a difficult addition, but it seemed like a beneficial path to pursue nonetheless.

Reviewer 3:
This reviewer recognized that the PI demonstrated that APEI team was working in close collaboration with Toyota, GaN Systems, NREL, and the University of Arkansas. The reviewer perceived the APEI team to be an excellent one with complementary capabilities drawn from partner companies to make overall team quite strong. The commenter stated that this should not only help in completing the project tasks, but also to achieve the project goals and DOE objectives 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:
This reviewer commented that most of the project goals were still in the future, but they seemed logical and achievable.

Reviewer 2:
This reviewer expressed that the future work appeared to be well-targeted and properly focused as this program moved toward final phases. The reviewer suggested that if DOE granted an extension, then wider inclusion of WBG suppliers would be a nice future goal.

Reviewer 3:
This reviewer stated that the PI identified relevant, yet challenging, tasks in the form of the proposed future work.

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

Reviewer 1:
This reviewer indicated that reducing the costs of EDVs would decrease petroleum use.

Reviewer 2:
This reviewer agreed that the research appeared to be consistent with DOE's objectives.

Reviewer 3:
This reviewer stated that the research was very relevant to DOE. The reviewer explained that technology advances in semiconductors appeared to be just a matter of time, so this work was very relevant. The reviewer thanked the presenter for a nice presentation.

Reviewer 4:
This reviewer indicated that if cost and performance objectives are met, WBG inverters designed, manufactured, and deployed across numerous applications could support reductions in the consumption of petroleum based fuels and energy resources in the United States.

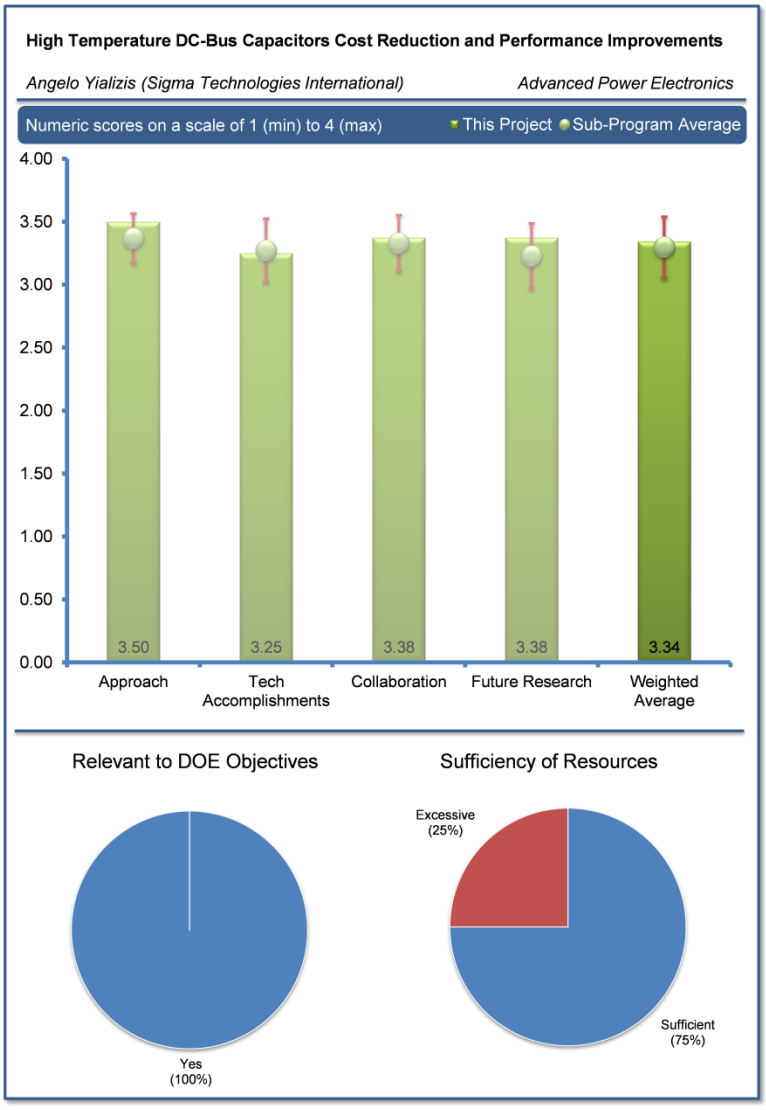
Question 6: Resources: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
This reviewer said that this was not addressed directly, but was presumably sufficient.

Reviewer 2:
This reviewer noted that the program appeared to be sufficiently resourced.

Reviewer 3:
It would have been interesting to this reviewer if the data were made available to see how the cost target of $182 unit cost (at an annual production volume of 100,000 inverters) was tracking. The reviewer explained that APEI lacked the mass manufacturing capability and infrastructure required to produce 100,000 WBG inverters per year. Thus, the reviewer was unclear as to how the $182 unit cost is tied with any manufacturing facilities needed, and also noted that this was not discussed in project report and/or in the presentation during the FY 2014 DOE Annual Merit Review.

High Temperature DC-Bus Capacitors Cost Reduction and Performance Improvements: Angelo Yializis (Sigma Technologies International) - ape059



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 highlighted that this looked like a very interesting approach. The reviewer is looking forward to the commercialization details.

Reviewer 2:

The reviewer reported that this project is developing a new process for capacitors with the intent of providing a more robust, smaller, and cheaper bus capacitor. This person stated that the plan was feasible and had a logical flow from requirements through development and testing to final product. The reviewer also concluded that the appropriate team members are assigned tasks in their areas of expertise.

Reviewer 3:

The reviewer described that this project would develop compact high-temperature polymer capacitors using an integrated manufacturing process. The reviewer explained that the unique machine can integrate the polymer formation, electrode deposition, and capacitor production in a single process to reduce the capacitor cost, while the vacuum-based deposition process can reduce the defects and improve the dielectric breakdown strength. The reviewer recognized that the project gets around the expensive and challenging thin-film manufacturing process as the dielectric layer is formed in-situ on a carrier. If successful, the reviewer asserted that the project had the potential to significantly reduce the size and weight of the DC link capacitors and the high temperature stability can be achieved by proprietary polymer chemistry. As the PI pointed out, the end connections may be very challenging as it is very difficult to end-spray molten particles to get connected to the thin metal layer as there is no "offset" as with the classical capacitor winding process. The reviewer emphasized that good electrical connections at the two ends are critical for the EDV application which requires high ripple current and low contact resistance. The reviewer also mentioned that the project proposed to use plasma etching to assist in the end connections, so it will be very interesting to this reviewer to see the test results as plasma may remove both the polymer and the thin metallization.

The reviewer voiced that achieving a high-speed coating process will be critical to reduce the capacitor cost, as the machine will cost greater than $10 MM. It was unsure to this commenter whether the UV or electron beam curing of 1 µm acrylate and the metallization could be completed in such a short time if the machine was running at 1,000 m/min. The reviewer also stated that high-voltage performance may also be a challenge, as the other two ends would be cut with a diamond saw and there may be a corona around the edges without un-metallized margins.

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 toward DOE goals.

Reviewer 1:
The reviewer commented that the team had demonstrated the capability to produce polymer multilayer capacitors for other low-voltage applications and the technology had been used by Japanese companies.

Reviewer 2:
The reviewer remarked that the project was just starting, but seemed to have a good starting point.

Reviewer 3:
The reviewer noted that this was a new project, and as such, did not have much to report on in terms of progress. The progress that was reported on was good and was consistent with the program plan.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer indicated that the collaboration team members appeared to be a good mix of industry and national laboratories.

Reviewer 2:
The reviewer commented that the team had a very strong experience in polymer film capacitor and power inverter design.

Reviewer 3:
The reviewer noted that the project was still at an initial stage, but the collaboration looked good. The reviewer offered that it seemed like it would be helpful to have a capacitor manufacturer involved.

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

Reviewer 1:
The reviewer remarked that the proposed future work aligned very well with the current progress and stated goals of this project. The reviewer affirmed that the next steps were a logical progression for the continued development to take place. The reviewer described that the plan had identified expected challenges but not decision points or alternative approaches at this time.

Reviewer 2:
The reviewer agreed that the proposed research was very critical to examine the several technical challenges that were raised in the "Approach" session where the end connection quality is sufficient for high ripple current and whether the cutting process will limit the operating voltage of the polymer multi-layer.

Reviewer 3:
The reviewer explained that the project was in initial stages, so most of the goals are in the future; however it looks like a good roadmap.

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

Reviewer 1:
The reviewer pointed out that improving the cost of EDVs would reduce petroleum displacement.

Reviewer 2:
The reviewer explained that the focus had been on high-temperature semiconductors, but now low-cost and high-temperature capacitors were required for EVs.

Reviewer 3:
The reviewer agreed that this task was relevant to the stated DOE objective of petroleum displacement, as it was addressing the need for a smaller, denser, high-voltage, high-temperature robust capacitors for use as a bus capacitor.

Reviewer 4:
The reviewer reported that the success of the project would produce compact high-temperature film capacitors to reduce the size of the EDV power inverters.

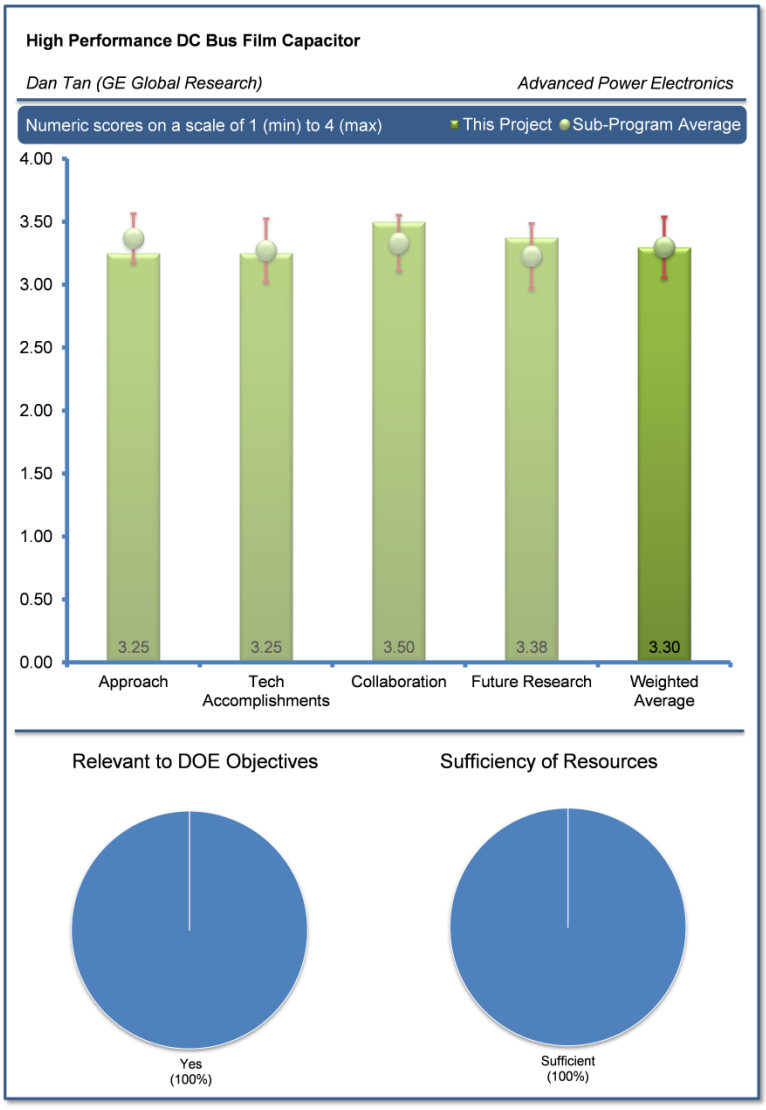
Question 6: Resources: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer agreed that the resources had been sufficient for the project to date, as the progress had been reasonable for a new program.

Reviewer 2:
The reviewer affirmed that the team had all the resources to work on the project in a timely fashion.

Reviewer 3:
The reviewer commented that the project resources were not described in detail, but looked to be sufficient.

High Performance DC Bus Film Capacitor: Dan Tan (GE Global Research) - ape060



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 concluded that this project had identified technical barriers and had a plan to succeed.

Reviewer 2:

The reviewer summarized that this project was developing a new process for capacitors with the intent of providing more robust, smaller, cheaper bus capacitors. The reviewer asserted that the plan was feasible and had a logical flow from requirements through development and testing to final product. The commenter reported that the approach was based on an internally-developed material, but will be using outside suppliers for support due to limited internal capacity access.

Reviewer 3:

The reviewer observed that Polyetherimide Ultem™ 1000 was one of the best polymers that could meet the technical performance requirement of the EDV DC link capacitor, while still having a relatively low cost. The reviewer noted the proposal to use extrusion to produce the film can potentially reduce the film cost. The commenter reported that the use of a carrier film to solve the winding issue would greatly improve the film quality. However, the reviewer commented, that the team should be aware of the potential cost of the carrier film.

Reviewer 4:

The reviewer commented that the approach was not explained in enough detail. It was clear to the reviewer that making thin films was critical, and that this led to good physical properties for capacitance, but it was not clear specifically how this work would lead to capacitors that meet the DOE targets. The reviewer also asked what the intermediate materials targets were.

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 toward DOE goals.

Reviewer 1:

The reviewer noted that this project appeared to be on schedule.

Reviewer 2:

The reviewer praised that the team had made impressive progress in producing thin capacitor film using Ultem™ 1000 resin with steadily improving quality over the years. The reviewer pointed out that this approach was low-risk compared with other technologies.

Reviewer 3:
The reviewer highlighted that this was a new project, but the reported progress was good and consistent with the program plan. The commenter agreed that the progress indicated that the approach was promising and that the development plan was reasonable. The reviewer mentioned that challenges were identified, but appeared to be manageable with the selected technology. The commenter stated that there was good progress in terms of the film shown from the previous work indicating a high probability of success at least as far as the film was concerned.

Reviewer 4:
The reviewer commented that it appeared that some materials production targets had been achieved, but it was not clear how much this contributed to achieving of the overall DOE goals. The reviewer suspected that this would improve as the project progresses; however should be maintained as a subject for future presentations.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer acknowledged that the team had very important members from the resin manufacturer, the dielectric engineers, the film production capability, and an EDV power inverter developing expert.

Reviewer 2:
The reviewer stated that the collaboration team members appeared to be a good mix of capacitor component suppliers and an automotive supplier. The reviewer suggested that adding additional capacitor suppliers to team in specific areas – should strengthen the team.

Reviewer 3:
The reviewer remarked that project team's collaboration was described at a high level, but not in detail.

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

Reviewer 1:
The reviewer explained that the project was at an initial stage, so most of the goals were in the future; in this sense there was a defined road map.

Reviewer 2:
The reviewer commented that the proposed future work aligned very well with the current progress and stated goals of this project. The reviewer noted that the next steps were a logical progression for continued development to take place. The commenter also indicated that the team had added collaborators with the required knowledge to continue the progress.

Reviewer 3:
The reviewer affirmed that the efforts to improve the film quality and reduce the film thickness were very important.

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

Reviewer 1:
The reviewer stated that decreasing costs would increase the sales of EDVs, leading to petroleum reductions.

Reviewer 2:
The reviewer agreed that this task was relevant to the stated DOE objective of petroleum displacement, as it was addressing the need for a smaller, denser, high-voltage, high-temperature, robust capacitors for use as a bus capacitor.

Reviewer 3:
The reviewer explained that the focus had been on high-temperature semiconductors, but now low-cost and high-temperature capacitors were required for EVs.

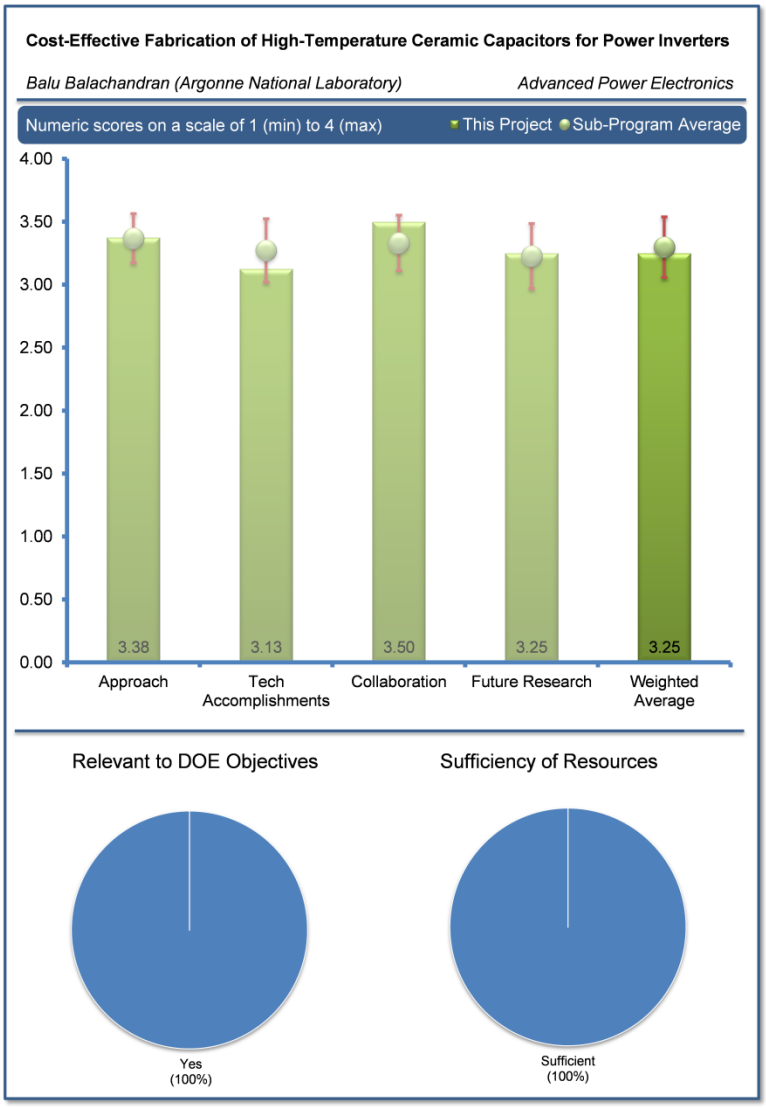
Question 6: Resources: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer reported that the resources had been sufficient for the project to date, as the progress had been reasonable for a new program.

Reviewer 2:
The reviewer noted that the team had all the resources to complete the project, though more investment on film extrusion facilities may speed up the project.

Reviewer 3:
The reviewer reported that the resources were not discussed in detail, but seemed to be sufficient.

Cost-Effective Fabrication of High-Temperature Ceramic Capacitors for Power Inverters: Balu Balachandran (Argonne National Laboratory) - ape061



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 explained that this project was developing a new process for capacitors with the intent of providing a more robust, smaller, and cheaper bus capacitor. The commenter indicated that the plan was feasible and had a logical flow from requirements through development and testing to final product. The reviewer described that the approach was based on different combination of materials on film than the previous capacitor projects reviewed this year.

Reviewer 2:

The reviewer commented that the lead zirconium titanate (PLZT) ceramic dielectric compositions developed by Argonne National Laboratory had excellent dielectric and high-voltage performance for DC link capacitors in EDVs. The commenter explained that the team proposed to overcome the low-breakdown in multilayer ceramic capacitor (MLCC) by using aerosol coating process to achieve high quality dielectric layer with high dielectric breakdown strength.

Reviewer 3:

The reviewer commented that the research seemed to be feasible and well-integrated with other efforts, but more information is needed to determine how the technical goals will lead to achieving overall DOE 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 toward DOE goals.

Reviewer 1:

The reviewer pointed out that this project had only just begun, but progress looked good.

Reviewer 2:

The reviewer indicated that this was a new project and that the progress that was reported on was good and was consistent with the program plan. The reviewer said that the progress indicated that the approach was promising and that the development plan was reasonable. The project evaluator reported that improvements in the thickness of the PLZT application have been made using a commercially-viable application method that indicated good potential for this project. The reviewer stated that the progress had been

made in the areas of cost-effectiveness by reducing fabrication time and the selection of the appropriate material. The commenter also recognized that the characterization data (from previous project) indicated that this approach was on the right track, and that progress was being made in the area of fabricating a more robust lower cost capacitor.

Reviewer 3:
The reviewer reported that the team demonstrated the capability to produce a thicker dielectric coating on metallized Kapton film and the coating had good performance. The reviewer explained that the team had initiated a roll-to-roll coating process which was required to fabricate the large size DC link capacitor in this project. The commenter remarked that the team shall be aware that the passive carrier substrate was much thicker than the active PLZT dielectric layer and the volume of the capacitor would be large.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer agreed that this work seemed very well-integrated with other organizations.

Reviewer 2:
The reviewer observed that the collaboration team members appear to be a good mix of national laboratories, university, Tier 1 supplier expertise, and fabrication process knowledge. The reviewer was concerned that two of the collaborators were on one of the competing capacitor development projects, and asked if the project team could support both with the appropriate resources when needed.

Reviewer 3:
The reviewer explained that the team had been actively working with the customer (Delphi) to test the prototype capacitor in EDC power inverters. The commenter also pointed out that Argonne National Laboratory was also working with Sigma who had impressive roll-to-roll processing capabilities.

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

Reviewer 1:
The reviewer affirmed that the proposed future work addressed the challenges that were identified during the progress to date. The commenter confirmed that important issues, such as failing benign, were being addressed early in the development. The commenter also emphasized that the early development of the final capacitor specifications was an important step in ensuring that the program would remain focused on the right final solution.

Reviewer 2:
The reviewer noted that most of the targets were still in the future, so in that sense the targets were well laid out.

Reviewer 3:
The reviewer acknowledged that while the thin carrier layer was required to perform the roll-to-roll production to convert the superior dielectric performance of the PLZT material to large-size packaged capacitors, the proposed 5 µm thick Kapton carrier film was not commercially-available. The reviewer explained that the thinnest Kapton film on the market was only 7.5 µm which costs $2,000/kg. The commenter suggested that the team may consider using low-cost substrates, such as aluminum foil, thin PEN film, etc.

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

Reviewer 1:
The reviewer confirmed that decreasing the cost of EDVs would increase sales and thereby decrease petroleum use.

Reviewer 2:
The reviewer agreed that this task was relevant to the stated DOE objective of petroleum displacement, as it was addressing the need for a smaller, denser, high voltage, high temperature robust capacitor for use as a bus capacitor.

Reviewer 3:
The reviewer stated that the capacitor was critical to achieving the DOE goal on EDV size, weight, and cost.

Reviewer 4:
The reviewer indicated that the focus had been on high-temperature semiconductors, but now low-cost and high-temperature capacitors were required for EVs.

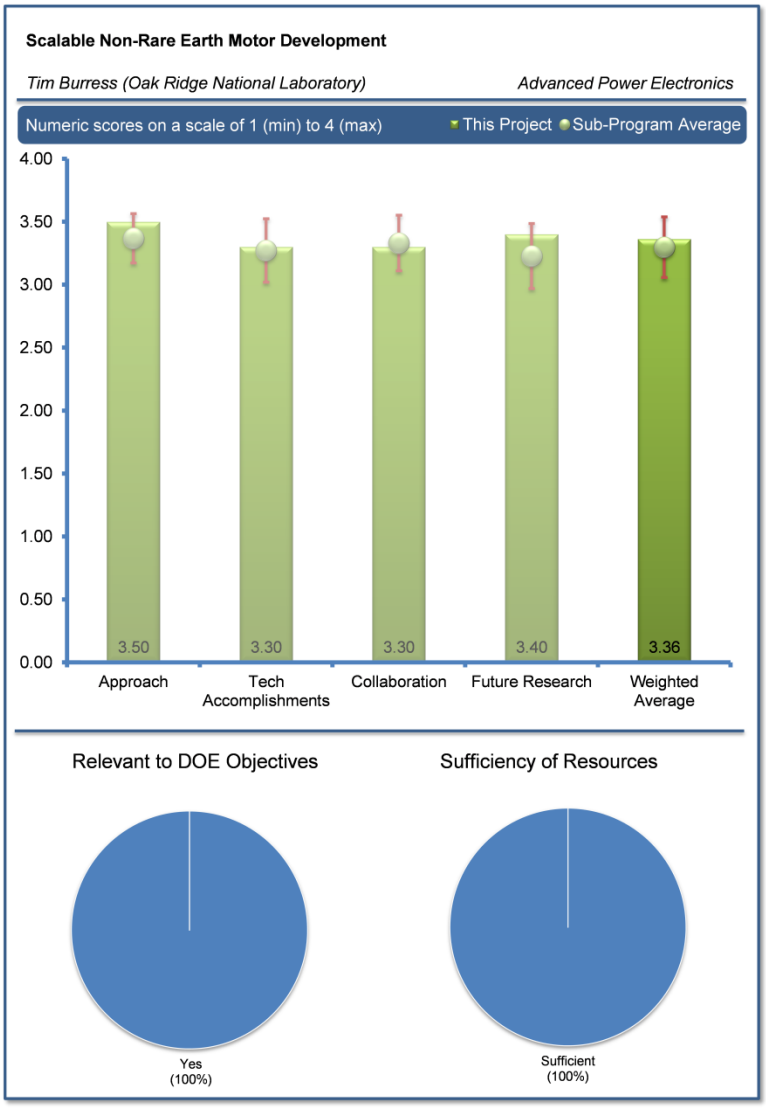
Question 6: Resources: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer noted that the resources were not discussed in detail, but seemed sufficient.

Reviewer 2:
The reviewer said the resources had been sufficient for the project to date, as the progress had been reasonable for a new program.

Reviewer 3:
The reviewer remarked that the team had strong capabilities on material characterization and capacitor test. The reviewer suggested that more resources might be necessary for roll-to-roll aerosol coating.

Scalable Non-Rare Earth Motor Development: Tim Burress (Oak Ridge National Laboratory) - ape062



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 stated that the approach to meet DOE targets had two main components, namely design of unconventional motor technologies starting from a comprehensive analysis of the major motor types and improving the performance of the soft magnetic material. The reviewer commented that compositional doping and new mechanical softening techniques were reported to have been employed to improve the workability of 6.5% Si steel material. The reviewer cautioned that the residual stress generated upon material cutting/stamping was also a matter of concern affecting the magnetization and permeability. The reviewer asked whether a low-temperature stress relief treatment would be considered to address this problem.

Reviewer 2:

The reviewer explained that this effort included fundamental research to improve three dimensional (3-D) finite element analysis (FEA) motor modeling accuracy (e.g., application of lamination stamping understanding and domain calculations) and their effect on lamination magnetic properties and micromagnetics software code. The project evaluator described that the initial simulations of novel designs would result in down-selection to the final design.

Reviewer 3:

The reviewer commented that the program might be too broad in scope, and if this led to a lack of focus and direction, it could fail to achieve useful results. The reviewer said that most of the presentation focused on high silicon content laminations, and if the electrical steel industry had difficulty creating this product at a lower cost it was difficult to see how this research would become a game-changer. The reviewer concluded by stating that electrical steel was big business. The reviewer encouraged the PI to continue looking for research elements that were not well covered right now. For example, most potting compounds were not ideal for motors (relatively high thermal resistance), so perhaps some materials work could be directed toward compounds and encapsulation that were better suited to motors.

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 toward DOE goals.

Reviewer 1:
The reviewer explained that the project was a continuation of development of high (6.5%) silicon steel using chemical vapor deposition, leading to a 40% reduction in core losses. The commenter cautioned that one drawback to this material was that it was more brittle and difficult to work with. The reviewer also explained that advanced analysis of the nonhomogeneous properties of magnetic steels were being observed through use of a custom measurement fixture which was helping to investigate the effect of punching, welding, etc. the commenter also described that scanning electron microscope analysis was being used to determine that stress/strain evident into laminations after punching (significant to ~150 □m). The reviewer explained that brushless field excitation and synchronous reluctance machines were among the most promising topologies being modeled, and the performance attributes were being evaluated compared to state-of-the-art hybrid-electric systems.

Reviewer 2:
The reviewer explained that the presentation was focused more on magnetic materials and analysis tools. The reviewer wondered why the non-RE material selection and improvements were not presented. The commenter also suggested that it would have been nice to see the details about the trade study results of machine types. The project evaluator asked the researchers what machine type would be considered for prototyping, and why.

Reviewer 3:
The reviewer pointed out that it was difficult to judge the accomplishments of a new program.

Reviewer 4:
The reviewer summarized that the team identified the 'next generation' synchronous reluctance and 'second generation' brushless field excitation motors as top choices for design optimization with a simulated torque and power performance comparable to 2010 Toyota Prius reference. The reviewer commented that not enough details were given on the respective designs, but the comparison charts showed a very good start of the program. The reviewer cautioned that the accuracy of the employed conventional FEA techniques may raise questions, and the implementation of the designs may bring out technical issues that are yet to be addressed.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer observed that the collaborators were the top experts for the ascribed tasks. During the presentation, the presenter mentioned that the team intended to draw from other material development activities outside the current collaboration, which was a very good strategy.

Reviewer 2:
The reviewer confirmed the good list of collaborators and their planned involvement in the program. The reviewer recognized that this collaboration may evolve as the program was further defined.

Reviewer 3:
The reviewer acknowledged that there was apparent core collaboration in this area, while respecting independent in the application between several of these DOE programs on this subject matter. The commenter highlighted that this synergy was necessary to achieve the objectives in motor development.

Reviewer 4:
The reviewer described that the industry collaboration partners included Remy (controls) and UQM (thermal management). The national laboratory partners include NREL (thermal management) and AMES (Non-Rare-Earth PM development/Beyond Rare Earth Magnets).

Reviewer 5:
The reviewer recommended that a couple of universities be added for collaboration to increase the depth and breadth of the team.

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

Reviewer 1:
The reviewer agreed that the future work was very clear on both motor design prototype and test, and electric steel material optimization.

Reviewer 2:
The reviewer recounted that the near-term goals included continued studies of deformation and residual stress impacts on electrical steel, development of code for analyzing magnetic domain propagation, and finalizing a proof-of-concept design. The first-stage prototype follows in FY 2015 with the final machine in FY 2016.

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

Reviewer 1:
The reviewer agreed that continued motor research and motor optimization would increase electrified vehicle market penetration, leading to reduced oil consumption.

Reviewer 2:
The reviewer stated that the proposed research would increase the efficiency of the non-RE PM machines; hence, this work would achieve better MPG or MPGe in the vehicle applications.

Reviewer 3:
The reviewer commented that the electrical machine technologies developed under this effort support further vehicle electrification and hybrid-electric applications, which would result in less fuel consumption. The reviewer explained that less RE content would significantly reduce the cost of advanced electric machines, contributing to increased adoption.

Reviewer 4:
The reviewer applauded the project team's nice work and looked forward to seeing the details of this project in the future.

Reviewer 5:
The reviewer referenced Question 1 comments, and cautioned that there are other innovative ways to increase lower speed efficiency aside from re-invented electrical steel. The reviewer suggested that looking for analogous technologies in other industries (e.g., internal combustion engines) could often help spur new ideas.

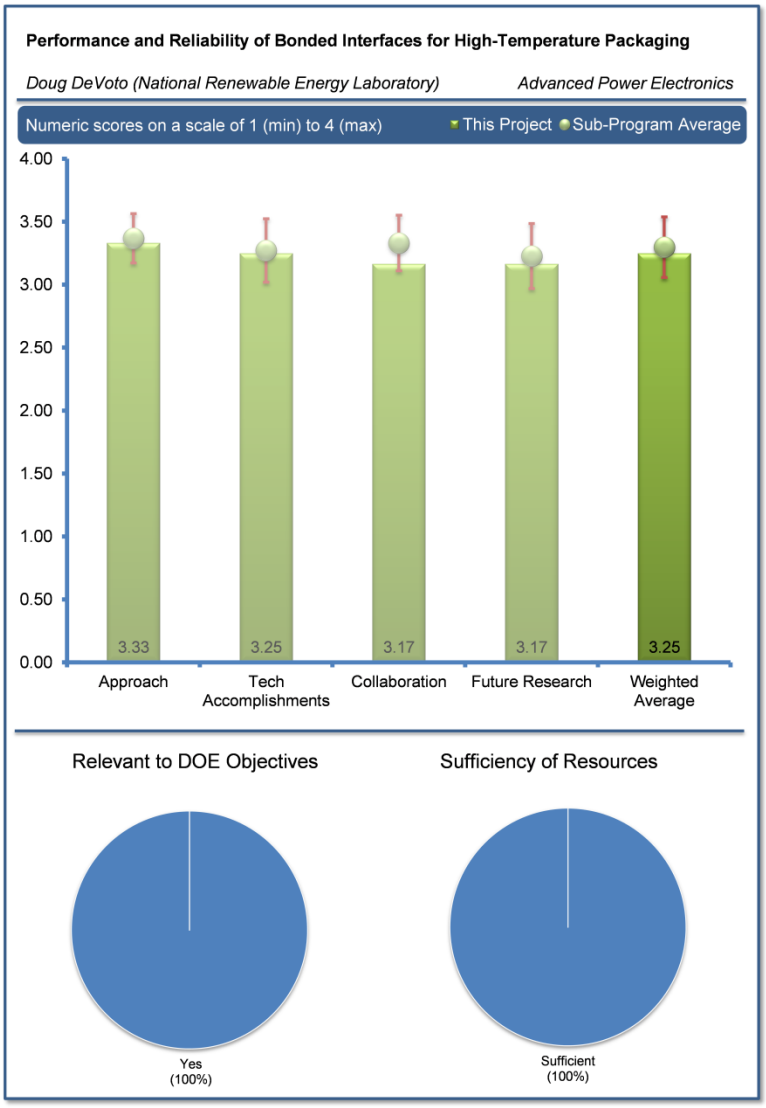
Question 6: Resources: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Reviewer 1:
The reviewer noted that ORNL had a good motor team, and combined with collaborators from other institutions; the resources should be sufficient for this program.

Reviewer 2:
The reviewer asserted that an impressive amount of analysis and advancement in FEA techniques was a part of this effort; thus a lack of resources was not apparent from the materials provided.

Reviewer 3:
The reviewer considered that the budget was sufficient for this project.

Performance and Reliability of Bonded Interfaces for High-Temperature Packaging: Doug DeVoto (National Renewable Energy Laboratory) - ape063



Reviewer Sample Size

A total of six reviewers evaluated this project.

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

Reviewer 1:

The reviewer indicated that this project was a new start and was likely to evolve with time. The commenter noted that the current work was focused on a sintered silver bond interface, but also suggested that it would be useful to consider including a brazed bond interface.

Reviewer 2:

The reviewer explained that the method proposed to determine the occurrence of delamination between various layers of different coefficient of thermal expansion materials in power devices was promising and could be useful to develop reliability and product durability models. However, the reviewer cautioned that the developed test samples needed to be thoroughly tested beyond 3,000 cycles. The commenter also commented that 5% delamination occurring after just 1,000 cycles may not be acceptable in certain applications. The reviewer encouraged the investigator to use alternative bonding material in power devices and then to assess the improvements in the elimination of early onset of the delamination phenomena. The reviewer also encouraged the application of bending force, while samples run through thermal cycling tests. The reviewer continued that this could be helpful to assesses if delamination process accelerates due to the presence of additional residual yet uneven distribution of forces in power electronics assembly. Apart from thermal cycling tests, thermal shock tests for assembly were also encouraged by the reviewer, if not already planned in the project.

Reviewer 3:

The reviewer emphasized that the interface modeling needed to be validated; however, the validation would be difficult because the simulation results (i.e., von Mises stress) cannot be directly measured in test. Hence, a better validation plan should be considered, especially if the model would be used for reliability analysis in the future work.

Reviewer 4:

The reviewer explained that this project was related to the fabrication of power modules using devices capable of operating at high temperature and what was required to enable these devices to do so reliably. The commenter indicated that this project was addressing the method of bonding devices to the substrate in a cost-effective and reliable method that can support high temperatures; currently this was an issue and would become a larger issue with the use of WBG devices. The reviewer described that the problem arises from a difference in the coefficients of thermal expansion of the materials and the resulting stress. The reviewer indicated the team was modeling

the stress and would then be performing testing to verify the model and processes developed. Finally, accelerated life testing would be performed to create recommended manufacturing processes for this joint. The reviewer expected that the end result would be a manufacturing process that allows the inverter to take advantage of high temperature operation without a loss in reliability.

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 toward DOE goals.

Reviewer 1:
The reviewer recognized that this project was a new start based on previous work which provided input based on modeling and test results from temperature cycling test samples. The reviewer recounted that, based on this data and new model was created and was being used to evaluate the stresses seen in the joint. The reviewer summarized that test samples with different coefficients of thermal expansion were created for use in testing to determine material and degradation characterization. In summary, the reviewer applauded the excellent start for the new project.

Reviewer 2:
The reviewer summarized that the investigator had carried out BIM testing, interface material/layer modeling, and preparation of test samples made of Invar and copper; both were also metalized with silver. The reviewer anticipated that BIM testing, interface material/layer modeling and preparation of test samples should facilitate a desired foundation for the project work and tasks in upcoming budget periods during FY 2015 and FY 2016. The reviewer questioned why it was desired to start module packaging work by selecting materials with different coefficients of thermal expansion. The reviewer also asked why attempts were not made to use materials with compatible and identical coefficients of thermal expansion.

Reviewer 3:
The reviewer noted that the work was in progress and was based upon a sound technical approach.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that the collaboration among team members was very good.

Reviewer 2:
The reviewer suggested that the effort would benefit from collaboration with power module manufacturers.

Reviewer 3:
The reviewer indicated that the investigator had identified project partners from ORNL, Heraeus, Henkel, and GM. As such, no details were provided, but this may be due to the project is in its early phase.

Reviewer 4:
The reviewer commented that the team had not demonstrated their expertise in model validation under uncertainty, uncertainty modeling and quantification, which were key elements in reliability analysis.

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

Reviewer 1:
The reviewer asserted that the investigator had identified quite challenging and relevant tasks for the future research and if carried out properly and in a timely manner these tasks had potential to offer excellent results during FY 2015 and FY 2016.

Reviewer 2:
The reviewer commented that the future work was centered on developing a stronger experimental correlation between interface patterning/degradation and junction temperature rise. The steps identified for this were appropriate to provide the data and insight required to enable this correlation to be performed. The reviewer indicated that once this correlation was understood, then it would be possible to develop a sinter-silver-based bonding process that was both reliable and met the cost goals.

Reviewer 3:
The reviewer commented that there was a lack details provided regarding their plan for validation and reliability work in the future. For example, the team would evaluate the delamination rate under various pressure requirements, bond areas, pad geometries, etc. The reviewer explained that without an effective reliability analysis methodology, these activities could be not only costly and time consuming, but could also provide little valuable information for the reliability analysis. The reviewer proposed that the team consider adding such expertise in the future collaboration.

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

Reviewer 1:
The reviewer highlighted that this project had the potential to solve reliability and durability challenges faced by present generation of power electronics. If life, reliability and durability challenges were properly understood and solved satisfactorily, outcomes of this project could increase confidence of industries involved in vehicle electrification activities and projects to develop products for EV and HEV based transportation systems. The reviewer agreed that project outcomes could support a net reduction in consumption of petroleum fuel.

Reviewer 2:
The reviewer confirmed that this task was relevant to the stated DOE objective of petroleum displacement, as it was providing a reliable and cost-effective bonding process for high temperature power modules which would enable smaller, lighter, and more efficient traction systems.

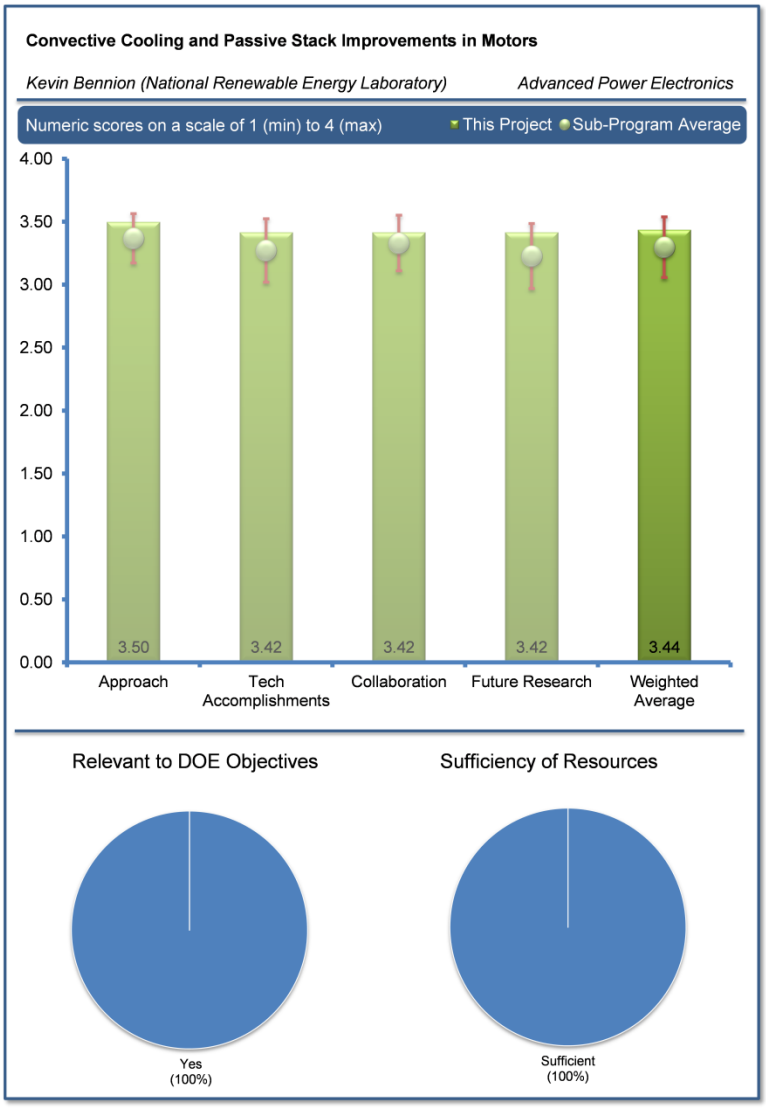
Reviewer 3:
The reviewer stated that high-temperature bonding was required on WBG circuits for EVs.

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

Reviewer 1:
The reviewer stated that the resources had been sufficient for the project to date for the progress had been carried out as planned.

Reviewer 2:
The reviewer encouraged the investigator to increase collaborations with the manufacturers of power electronics parts, devices, and systems solutions.

Convective Cooling and Passive Stack Improvements in Motors: Kevin Bennion (National Renewable Energy Laboratory) - ape064



Reviewer Sample Size

A total of six reviewers evaluated this project.

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

Reviewer 1:

The reviewer agreed that the work plan had used a very systematic and logical breakdown of the cooling mechanisms in electric machines, and made very good use of input from manufacturers and users of motors in industry, to make sure that final outcome of research would be useful to the industry.

Reviewer 2:

The reviewer remarked that this program was well-conceived, starting with the evaluation of the many orthotropic regions of the motor through experimentation. The commenter reported that the pros and cons of the cooling strategies were also well-understood, with foresight shown regarding some of the "hidden" challenges (e.g., heat at the center of the stack with oil spray cooling).

Reviewer 3:

The reviewer noted that the thermal management technologies to be developed by NREL, and the corresponding analysis, was intended to be conceptually applicable to various motor configurations, although different operating conditions may require specific design. The reviewer asked whether the team was sharing the information on the splatter effect with increasing velocity and temperature, with the automatic transmission fluid manufacturers. The reviewer wondered if there was there any work on improving the performance by increasing the viscosity and decreasing the surface tension, while retaining excellent thermal conductivity.

Reviewer 4:

The reviewer stated that this was a FY 2014 start project that was focused on thermal management of electrical machines. Consideration was being made with regard to the cooling fluid, PMs, insulation system, efficiency, operating temperature, etc. The reviewer described that the objectives included data, analysis methods, and experimental techniques to improve and better understand motor thermal management. Analysis was being conducted to exploit the orthotropic (direction-dependent) thermal properties of the materials in the machine. Heat transfer coefficients were being determined. The primary focus was on the stator system to be applicable to as many machine types as possible. The reviewer noted that active rotor cooling was not a focus area, despite significant concerns with the PMs, so the reviewer indicated that additional attention would be useful in this area especially due to the push to reduce PM Dy content, lowering the operating temperature.

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 toward DOE goals.

Reviewer 1:
The reviewer noted the good work so far developing rigorous test methods for measuring convection and directional conduction properties of windings and lamination stacks.

Reviewer 2:
The reviewer recognized the good start to this program, with a variety of tests already performed and others on deck to be performed. The commenter noted that it was good to see a program that got out of the gates quickly.

Reviewer 3:
The reviewer lauded the significant project accomplishments including the oil impingement test apparatus and results, with consideration to different surface treatments. Additionally, the reviewer mentioned that data was being collected related to lamination-lamination thermal contact resistance determined as a function of pressure, with consideration to the impact of varying numbers of laminations. Measurement of thermal conductivity of in-slot wire bundles with different fill factors was also being completed. The reviewer highlighted that one interesting finding discussed was that the splattering of coolant results in more random heat transfer properties compared to more uniform flow.

Reviewer 4:
The reviewer noted that the milestones seemed to have been met on schedule. The commenter explained that the major milestones for this reporting period were on measuring the automatic transmission fluid heat transfer convection coefficients on target surfaces and orthotropic thermal conductivity. The reviewer suggested that guidance be provided for the lamination material (i.e., thermal resistance, surface roughness, and number of stacks) to ensure effective thermal management. The reviewer also indicated that an analysis of potting materials has not yet been done.

Reviewer 5:
The reviewer suggested including concentrated winding types to the study as some car manufacturers use motors with concentrated windings. The commenter also explained that in motors, typically it was possible to incorporate RTD or other thermal sensors inside the stator to monitor the stator temperature; however, measuring the rotor temperature is not practical. So the reviewer voiced that it would be a great contribution if this project covered the prediction of rotor temperatures. The commenter suggested including modeling and analysis of PMs for thermal characterization.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer agreed that there was a very good combination of industry and government laboratory resources that brought a wealth of knowledge to bear on the subject. The project evaluator confirmed that the work appeared to be well-coordinated, and researchers appeared to be responsive to input from industry, and making mid-course adjustments as needed.

Reviewer 2:
The reviewer acknowledged the good collaborators with other laboratories and history suggests that the PI would also engage industry throughout the project.

Reviewer 3:
The reviewer pointed out that the key collaborator in this work was ORNL, with support from the HEV benchmarking activity, motor design expertise, and materials development. The reviewer also acknowledged that significant industry partnerships providing input and exchanging data include Ford, Chrysler, Tesla, UQM, Remy, and Magna.

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

Reviewer 1:
The reviewer agreed that the proposed combination of experimental work and computational fluid dynamics for test correlation made good sense, and this would maximize value of research to industry.

Reviewer 2:
The reviewer recognized that the future work was well-conceived and the reviewer was looking forward to the insights obtained from the research, especially the effect that orthotropic properties had on the temperature through the length of a motor. The reviewer also noted that almost all of the temperature sensors were placed somewhere in the end windings, independent of the cooling method.

Reviewer 3:
The reviewer commented that the proposed future work was very well-defined, but to their understanding was limited to analyzing the current conventional thermal management technologies and testing their efficiency, rather than to elaborating new concepts or technologies. The reviewer asked whether the concept of heat pipes would be applicable, or introduce excessive weight.

Reviewer 4:
The reviewer explained that the near-term plans included further analysis based on automatic transmission fluid data, simulation and model validation of impinging fluid jets, and end turn thermal analysis. The commenter also noted that the FY 2015 goals included further end turn analysis and motor in-situ measurement of thermal resistances.

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

Reviewer 1:
The reviewer agreed that thermal management was a key technology for improving power/torque density and reliability of electric machines, and reducing the heavy RE content in PM motors. The commenter stated that both of these objectives supported the widespread use of EVs, and therefore petroleum displacement.

Reviewer 2:
The reviewer confirmed that thermal management was critical to electrified vehicles. The commenter explained that poor thermal management may lead to reduced life and low reliability, so this research would help electrification market penetration, and thus reduce oil consumption.

Reviewer 3:
The reviewer asserted that the electrical machine technologies developed under this effort supported further vehicle electrification and hybrid-electric applications, which would result in less fuel consumption. The commenter also stated that improved thermal management would result in less thermal burden on the vehicle cooling system, thereby improving overall powertrain efficiency.

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

Reviewer 1:
The reviewer stated that the resources seemed well-matched to the stated objectives.

Reviewer 2:
The reviewer said that the resources for this program appeared to be sufficient.

The reviewer considered the budget to be sufficient for this project. However, if new cooling concepts will be explored, extra funds may be needed.

Reviewer 3:

The reviewer noted that an impressive amount of analysis and advancement in thermal management techniques was a part of this effort. Thus, a lack of resources was not apparent from the materials provided.

Acronyms and Abbreviations

Acronym	Definition
3-D	Three-dimensional
Al	Aluminum
APEEM	Advanced Power Electronics and Electrical Machines
B	Boron
BIM	Bonded Interface Material
Co	Cobalt
DC	Direct Current
DOE	Department of Energy
Dy	Dysprosium
EDR	Eigenvector dimension reduction
EDV	Electric Drive Vehicle
EE	Energy efficiency
EV	Electric Vehicle
EVSE	Electric vehicle supply equipment
Fe	Iron
FEA	Finite Element Analysis
FY	Fiscal Year
GaN	Gallium Nitride
GE	General Electric
GM	General Motors
HEV	Hybrid Electric Vehicle
kW	Kilowatt
kV	Kilovolt
MGOe	Megagauss-oersteds
MLCC	Multilayer ceramic capacitor
MPG	Miles per gallon
MPGe	Miles per gallon-electric
Nd	Neodymium
Ni	Nickel
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PI	Principal Investigator
PLZT	Lead Zirconium Titanate
PM	Permanent Magnet
R&D	Research and Development
RE	Rare Earth
RPM	Rotations Per Minute

Acronym	Definition
Si	Silicon
SiC	Silicon carbide
V	Volt
VTO	Vehicle Technologies Office
WBG	Wide Bandgap
Zn	Zinc

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