3. Electric Drive Technologies

Electric drive technologies, including the electric motor, inverter, boost converter, and on-board charger, are essential components of hybrid and plug-in electric vehicles (PEV) propulsion systems. The U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) supports research and development (R&D) to reduce the cost and improve the performance of innovative electric drive devices, components, and systems. Reducing the cost of electric drive vehicles is essential for increasing consumer adoption and meeting the *EV Everywhere* Grand Challenge goal of making the U.S. the first nation in the world to produce PEVs by 2022 that are as affordable for the average American family as gasoline-powered vehicles in 2012.

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

- Power electronics
- Electric motors

VTO funds research on electric drive technologies to:

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

In addition, VTO is also supporting research on propulsion materials to lower adoption barriers for electric drive technologies that face specific material limitations. More information on these research and development activities can be found in the Annual Merit Review and Annual Progress Reports.

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

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

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

- The U.S. DRIVE Partnership focusing on light-duty vehicles
- The 21st Century Truck Partnership, focusing on heavy-duty vehicles.

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

Subprogram Feedback

DOE received feedback on the overall technical subprogram areas presented during the 2015 Annual Merit Review (AMR). Each subprogram technical session was introduced with a presentation that provided an overview of subprogram goals and recent progress, followed by a series of detailed topic area project presentations.

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

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

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

Question 3. Were important issues and challenges identified?

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

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

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

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

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

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

Question 10. Has the program area engaged appropriate partners?

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

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

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

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

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

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

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

Subprogram Overview Comments: Steven Boyd (U.S. Department of Energy) – edt000

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

Reviewer 1:
The reviewer said that the DOE Vehicle Technologies Office (VTO) Electric Drive Technologies program and strategy was adequately covered in this presentation. The program goal was clearly identified and the strategy as to how the problem was being solved was presented. The reviewer said that the overall strategy is to develop technologies and designs to reduce the cost, improve the performance, and increase the reliability of power electronics, electric motors, and other electric propulsion components. The reviewer said that this task is split into a research and development (R&D) area and a Funding Opportunity Announcement (FOA) area with the goal of the R&D results feeding the FOA projects. The R&D tasks are focusing on wide bandgap (WBG) development and reducing rare earth magnets in motors, both required to meet the program goals. The end result is specified along with the steps required to achieve it. The reviewer found that overall, the program area was very well covered.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer said yes, the program overview was effective and the overall strategy clearly explained and the justification of pursuing the proposed strategy clearly explained as well.

Reviewer 4:
The reviewer said yes, the program area and strategy are well directed.

Reviewer 5:
The reviewer said yes. The reviewer elaborated that cost and technical targets were clearly explained and the program's strategy and progress were highlighted well.

Reviewer 6:
The reviewer said that the program area and overall strategy was well covered and it is clear to the audience what the program is working on.

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

Reviewer 1:
The reviewer remarked yes, it does have appropriate balance.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer said yes. The reviewer detailed that some of the research efforts, such as WBG semiconductors and novel motor designs, can have immediate impacts. Other areas, such as magnetic materials development, are much needed long-term endeavors.

Reviewer 4:
The reviewer said yes. The reviewer detailed that the program strategy includes: meeting the Electric Vehicle (EV) Everywhere Grand Challenge, a 10 year goal; WBG semiconductor-related technologies, including packaging, converter, and system technologies that have near-, mid-, and long-term R&D outcomes; non rare-earth motor R&D, which is a mid- to long-term research goal based on the need to re-think business strategies in response to disruptions in the market of rare-earth magnets; and near- to mid-term industrial R&D in inverters and motors.

Reviewer 5:
The reviewer detailed that the projects presented during the Annual Merit Review included projects nearing conclusion, projects in the middle of development, and new projects. These projects included both R&D and FOA projects. The reviewer described that this presentation also included previous projects that had successfully transitioned to production or had been licensed for further development. Some of the projects are addressing specific issues or single components, but are related in terms of providing a solution to the overall problem. The reviewer noted that other tasks are related to new architectures that will use the projects of today to deliver more efficient and cost effective vehicles in the future.

Reviewer 6:
The reviewer said yes, there is a very good balance between near-, mid-, and long-term R&D. The reviewer's suggestion is to start a new cycle of projects that are fairly mid- to long-term to keep pushing the state of the art.

Question 3: Were important issues and challenges identified?

Reviewer 1:
The reviewer said yes.

Reviewer 2:
The reviewer said absolutely, and clarified that the program develops targets for the improvement of electric drive system components (cost, size, weight, and loss), as needed to meet the EV Everywhere Grand Challenge goals of reduced cost, size, weight, and cost.

Reviewer 3:
The reviewer agreed that the challenges in terms of specific power density, efficiency and cost were clearly identified.

Reviewer 4:
The reviewer said yes, and elaborated that a primary challenge for electric drive technologies is cost reduction.

Reviewer 5:
The reviewer said that the presentation did a very good job of identifying the leading issues/challenges facing the electric vehicle development world. The research in the area of reducing/eliminating rare-earth magnetics is a very good example. The reviewer detailed that the supply of these magnetics is limited and therefor the price is highly volatile, while the development of a magnet from more abundant materials and motor designs that can effectively use it will enable a more cost effective system to be produced. The reviewer identified he development of WBG switches as a challenging area. These devices are capable of very fast switching, but this brings a host of other challenges: how these devices are driven/controlled; how the heat is removed; and how these devices are packaged, to name a few.

Reviewer 6:
The reviewer said yes.

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

Reviewer 1:
The reviewer said yes. The program includes R&D focus areas in adoption of WBG semiconductors and their application, and in development of non-rare-earth motors.

Reviewer 2:
The reviewer said that several plans were identified for cost reduction, including the adoption of WBG semiconductors and motor technologies that do not use rare-earth magnets.

Reviewer 3:
The reviewer said that the projects in the two main areas of focus were clearly identified in the presentation. The goal as well as the expected results were documented, and the current status of these projects was shown. The reviewer remarked that it was clear that significant effort has been aimed at these areas and results were seen with more advances to come.

Reviewer 4:
The reviewer said yes.

Reviewer 5:
The reviewer said yes.

Reviewer 6:
The reviewer said that it is clear how ongoing programs are trying to address these challenges, but with several of the current programs are coming to an end within the next year or two, and it was not very clear what the next batch of projects will target.

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

Reviewer 1:
The reviewer said yes, very much so.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer said that results were clearly highlighted, although it was necessary to dig a little to identify this year's new results relative to last year's. Most projects in the program are very good in this regard, while a few are vague in identifying and benchmarking their results.

Reviewer 4:
The reviewer noted that several research accomplishments were clearly presented. However, it was not obvious to this reviewer that they were accomplished since the previous year. The reviewer indicated that after reviewing the 2014 presentation, the accomplishments appear to be recent.

Reviewer 5:
The reviewer remarked to some extent, but it would be good to show quantitatively how the various projects are progressing the various performance metrics/targets

Reviewer 6:
The reviewer said that this presentation did not specifically benchmark progress relative to last year with the exception of the current status on Slide Seven, which indicated $12/kW while last year it was at $15/kW versus the goal of $8/kW. The presentation concentrated on what was accomplished this year, which was significant.

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 remarked yes, clearly identified.

Reviewer 2:
The reviewer said yes, very important barriers for the VTO.

Reviewer 3:
The reviewer said yes, these projects are the primary barriers to reducing cost and increasing performance of electric drive technologies.

Reviewer 4:
The reviewer said yes, the program has a diversified set of programs that address many of the identified barriers

Reviewer 5:
The reviewer said yes, and elaborated that the projects target reductions in the cost, size, weight, and loss of the electric drive systems of electric vehicles, which are key barriers to the EV Everywhere Grand Challenge.

Reviewer 6:
The reviewer said that the projects are focused on solving specific issues by providing not only specific issues but also providing the tools and knowledge necessary to adapt these solutions to meet the needs of an individual problem. The projects are focused on how to use a device, create a common sub-component, such as a capacitor, or a process to design, and effective thermal system that can be used or modified by different industry suppliers to meet their product needs. The reviewer said that in the motor area, non-rare earth magnetics with specific properties are being developed as well as motor topologies that are capable of using these magnets to meet performance goals. Other projects are addressing new and novel electric traction system implementations featuring higher levels of integration or more user friendly charging techniques.

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, the program is focused and well-managed. The key challenge is the strategic planning part to ensure that future projects will continue to be relevant and address the key challenges and barriers.

Reviewer 2:
The reviewer said yes, and elaborated that several key barriers have been identified and multiple research projects are addressing each area.

Reviewer 3:
The reviewer said yes, the program is well managed. The reviewer explained that over the past few years this reviewer has seen programs stopped that were not making progress toward the documented goals as well as projects that have made it to real world production. The reviewer confirmed that all of the projects are related to solving the EV Everywhere Grand Challenge. Some are more high-risk but with big payoffs than others, but all are focused on the end goal.

Reviewer 4:
The reviewer said yes.

Reviewer 5:
The reviewer said yes.

Reviewer 6:
The reviewer said 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 said that the projects supported by VTO covers the most important technologies in electric vehicles and VTO is pushing for both technology advancement and cost reduction. The reviewer expressed concern that the available funding may not be sufficient to solve the targeted problems.

Reviewer 2:
The reviewer identified two projects that stood out: the funding of the Delphi Viper module, which is being integrated into the 2016 Chevy Volt using silicon devices; and Next Generation Wide Bandgap Packaging Improves Inverter Efficiency (Oak Ridge National Laboratory [ORNL]). What is attractive about these two projects are the focus on improved packaging of silicon carbon (SiC) power devices for automotive inverters, and the direct involvement of a Tier One (Delphi) automotive supplier.

Reviewer 3:
The reviewer believed that the shotgun approach to pursuing multiple approaches to meet well-defined overall goals is a good one. DOE's role should indeed be one of pursuing a portfolio of projects in which some have high risk but high potential reward. The reviewer identified the capacitor technology direction of the past few years as a good example. All of the several projects have been well directed, and this year it appears that at least one of them is going to be a winner that could have a significant impact on EV technology (and on other industries as well).

The reviewer explained that the recent projects in electronic packaging have spanned a wide range of quality: some have had a significant impact on wide bandgap modules for the industry, or have led to fundamental new understandings that can have a future impact. For others, the results have been vague. The reviewer noted that the projects in inverters and chargers, and in machines, appear to be going well so far. These span a wide range from shorter-term industrial projects to longer-term projects at laboratories or universities, which is appropriate. The work in non-rare-earth magnets should be continued.

Reviewer 4:
The reviewer commented that wide-bandgap semiconductors are becoming mainstream, but still require some development in the packaging area to reliably operate at high temperatures. Capacitor technologies are the next big issue in power electronics systems. The reviewer noted that moving away from rare-earth magnets in motors is also a key area to reduce cost. The majority of projects are addressing these areas. Understandably, the program focuses on near- to mid-term issues, but the reviewer would like to see a few more long-term research efforts.

Reviewer 5:
The reviewer said that the key strengths of the projects are that they are well-diversified and almost all of them build prototypes and provide experimental results. The reviewer said that the key weakness is that these projects need to be tied together and optimized at the system level to evaluate the realistic improvement at the system level.

Reviewer 6:
The reviewer said that the key strength is that all of these projects are aimed at solving a common problem but are attacking different areas to achieve a common solution. The use of WBG devices will create challenges in terms of how to drive power devices at high switching frequencies and still maintain fault protection, what are the package requirements to enable high temperature, reliable operation and still support high switching speeds, how do you maintain operating temperatures in a safe range all while lowering the overall cost of the system and increasing the efficiency. The reviewer noted that the projects identified are addressing these issues in such a way that the industry supplier still has freedom to implement the system in accordance with their internal design rules. According to the reviewer, the weakness is in areas that are broader in nature such as new system topologies. These projects are beneficial in that they are challenging the status quo in terms of what the system

implementation should be but do not always address all of the issues or minimize the impact on the individual components. Even these projects have benefits to the overall program in forcing a re-thinking of the status quo.

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

Reviewer 1:
The reviewer said yes, and explained that the ORNL effort allows the use of additive manufacturing, advanced packaging techniques, to improve power density with SiC. The Delphi Viper module is perhaps one of the best chances the United States has for a domestic Tier One automotive supplier to lead development of future electric vehicles.

Reviewer 2:
The reviewer said that yes, most of the projects are innovative and try to address the barriers.

Reviewer 3:
The reviewer said in general, yes.

Reviewer 4:
The reviewer said yes, the projects provide novel solutions to the program's targets.

Reviewer 5:
The reviewer said that using additive printing on the development of a SiC based inverter was novel and innovative – it provided a quick path to demonstrate the design. While not ready for high-rate production this does provide a path to enable fast turnaround on early development projects whether they are the R&D or the production world. The reviewer noted that several of the motor projects represent very innovative approaches to motor design without rare earth magnets and are showing excellent promise of replacing rare earths. Other projects are developing novel methods for cooling components, testing them, and in the development of manufacturing processes. The reviewer thinks that most of the projects are novel/innovative in their approach, their solutions or both.

Reviewer 6:
The reviewer said the projects do balance the innovation and practical feasibility.

Question 10: Has the program area engaged appropriate partners?

Reviewer 1:
The reviewer said yes, there are many projects with multiple partners across the supply chain.

Reviewer 2:
The reviewer said yes, efforts appeared to involve leading suppliers across the supply chain. SiC device manufacturers (not specified, but assumed Cree), module teams (APEI module shown), Tier One automotive suppliers (Delphi), and original equipment manufacturers (Chevrolet).

Reviewer 3:
The reviewer said yes, the program engages a wide range of relevant partners from industry, academia and national laboratories.

Reviewer 4:
The reviewer said yes, and explained that teams are emphasized throughout the program, which include companies, national laboratories, and universities.

Reviewer 5:
The reviewer said yes, and detailed that the program has a wide range industry, federal agency, academia, and national laboratory affiliations.

Reviewer 6:
The reviewer found that the teams have the appropriate partners for their specific project. Some of the collaboration partners may not be fully utilized during the entire project but are available when needed. The reviewer highlighted that in some cases, the teams may be lacking a specific expertise or have not identified the need for it yet, and this is pointed out during the review process. In general, the teams consist of the necessary people and appear to be effectively using this expertise.

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

Reviewer 1:
The reviewer commented that based on the progress of the various projects this reviewer thinks the program area is effectively collaborating with the teams. The projects, while separate, are still working toward a common goal and there appears to be very good cooperation among the national laboratories on these projects.

Reviewer 2:
The reviewer said yes.

Reviewer 3:
The reviewer said yes.

Reviewer 4:
The reviewer said yes.

Reviewer 5:
The reviewer said generally yes, and detailed that the aluminum-nickel-cobalt (AlNiCo) collaboration appears to be a good example of collaboration.

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

Reviewer 1:
The reviewer said none observed.

Reviewer 2:
The reviewer said that the portfolio makes sense.

Reviewer 3:
The reviewer did not notice any gaps.

Reviewer 4:
The reviewer is not aware of any gaps.

Reviewer 5:
The reviewer suggested more system level projects tying the various components together, more focus on enabling technologies including magnetic materials and thermal management but in the context of actual components, and more focus on true tight integration of the motor and power electronics especially enabled by WBG devices.

Reviewer 6:
The reviewer commented that the largest observed gap is regarding cost-effective connectors for high-voltage power that meets automotive requirements. The reviewer is not sure if this is even appropriate for this forum, but that is the one area where the reviewer has not seen any advances – typically use lug terminals, which are okay, but connectors would enable faster assembly at the vehicle level but need to perform in all areas – safety, weather protection, and cost. The reviewer presently believes the portfolio is adequate but as the development of WBG-based power electronics advances there may be some new areas that will need addressing. The reviewer is sure that these areas will be addressed in future projects as appropriate.

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

Reviewer 1:
The reviewer is not aware of any topics not being adequately addressed.

Reviewer 2:
The reviewer concluded that the primary technical barriers are being adequately addressed.

Reviewer 3:
The reviewer said that the program should continue to solicit new research directions that are outside the current thinking, but there are no glaring oversights in directions.

Reviewer 4:
The reviewer recommended that more involvement of automotive Tier One suppliers in WBGs is needed. Globally, it will be Delphi, Bosch, Magna, Denso, and others that lead the introduction of SiC into electric vehicles. The reviewer noted that Toyota has already announced SiC will be in the Prius by model year 2020.

U.S.-based Tier One suppliers like Delphi and Magna can supply OEM's around the world with SiC or gallium nitride (GaN)-based power systems, from inverters, direct current-direct current (DC-DC) converters, and on-board chargers. The reviewer observed that in some cases Tier Two suppliers or OEM's may also directly use the WBG in their systems, but the Tier One suppliers will have the biggest impact, and must be more actively involved in the introduction of SiC domestically for the drivetrain to match efforts ongoing in Japan and Germany primarily.

Reviewer 5:
The reviewer believes that some of these areas are addressed but the level of effort is not adequate.

Reviewer 6:
The reviewer thinks that the only topic that is not being adequately addressed is integrating these systems in the vehicle but this is typically the responsibility of the OEM. The reviewer's concern is that the integration will have a significant effect on the implementation of the system – how much space is available, what shape, etc. The reviewer sees generic requirements such as voltage, power, etc. and a desire to reduce size and mass, but not much in terms of how to interface to a battery or the rest of vehicle. The reviewer noted that some of the requirements provided to the capacitor projects are not representative of some of the newer architectures: boosted systems may have a 650 volt or higher high-voltage bus while most of the capacitor programs are aimed at 600 volts or less. The reviewer is unsure if the constraints of the end-use are fully understood, such as the typical requirements for particle size in coolant systems – will the jet impingement-based cooling survive these particles or will an extra filter be required or will this work with the standard pressure/flow rate of today's coolant systems.

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

Reviewer 1:
The reviewer said no.

Reviewer 2:
The reviewer presently does not see any significant benefit to adding areas to this program. The reviewer believes the focus is on the correct areas, and this should be revisited in the coming years as electric vehicle technology progresses.

Reviewer 3:
The reviewer stated that for most electric vehicle adoption, based on Tesla, BMW, Lexus, and others, it seems like much of the initial adoption of SiC in the drivetrain is occurring at the high-end of the performance

spectrum. The reviewer therefore suggests inverter targets be set with higher power levels, 100-300kW, with increased SiC die sizes, and increased involvement of Tier One suppliers. The reviewer stipulated that the higher-end vehicles normally are the first to adopt new, relatively expensive technology, and based on the Tesla model it is clear that customers will pay for high-end performance and quality electric vehicles.

The reviewer pointed out that the market is seeing strong interest, especially from Tesla and international OEM's and Tier One's, in the higher-power inverter area utilizing SiC in the drivetrain.

Reviewer 4:
The reviewer suggested more system level projects tying the various components together, more focus on enabling technologies including magnetic materials and thermal management but in the context of actual components, and more focus on true tight integration of the motor and power electronics, especially enabled by WBG devices. The reviewer also suggested fault-tolerance/limp-home mode capability aspects, and monitoring and diagnostics of the electric drivetrain components including insulation, bearings, transmission, etc.

Reviewer 5:
The reviewer suggested maybe investing in projects that can demonstrate the technical feasibility at vehicle level.

Reviewer 6:
The reviewer suggested high-frequency magnetics research for power converters could be a good addition, although that may not be a priority since other technologies are also limiting the operating frequency.

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

Reviewer 1:
The reviewer had no additional recommendations other than what was mentioned in questions 13 and 14.

Reviewer 2:
The reviewer said that the program is aligned well to the near- and mid-term barriers for electric drive technologies. The reviewer suggests increasing focus on some of the long-term areas, such as magnetic materials development.

Reviewer 3:
The reviewer suggested more system-level projects tying the various components together, more focus on enabling technologies including magnetic materials and thermal management but in the context of actual components, more focus on true tight integration of the motor and power electronics especially enabled by WBG devices. The reviewer also suggested fault-tolerance/limp-home mode capability aspects, and monitoring and diagnostics of the electric drive train components including insulation, bearings, transmission, etc.

Reviewer 4:
The reviewer emphasized that it is important to continue to emphasize cost, but very few of the projects were able to measure the real cost, because the projects constitute mid- to long-term research where the cost cannot be directly measured, only the more near-term industrial projects had a realistic chance of truly measuring cost. The reviewer underscored that this is understandable. Perhaps there should be some effort to define intermediate metrics that are related to cost but are not simply $/kW, which would help guide the mid- and long-term R&D.

The reviewer said that on the whole, the projects were more successful in quantifying performance. The goals regarding performance (weight, volume, loss) could perhaps be expanded to consider the system as a whole. The reviewer provided as examples, as noted in this year's and last year's program presentations, look for ways to expand the range of high efficiency of the overall system, or to improve the overall size and weight, rather than the inverter alone or the machine alone.

Reviewer 5:
The reviewer found that the current approach to barriers at the program level is working – barriers are being broken and progress is being made as long as the barriers being addressed at the individual project level are correct.

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

Reviewer 1:
The reviewer suggested continuing to support disruptive game-changing technologies that can make a step change in the state of the art.

Reviewer 2:
The reviewer suggested the following in the electronic packaging area: continue to nurture the WBG industry to develop good power modules as appropriate for the future EV business; and focus the national laboratories on producing fundamental results, models, and tools that are useful to the industry, or in pursuing specific collaborations led by industry.

Reviewer 3:
The reviewer has no further suggestions.

Reviewer 4:
The reviewer suggested that adding additional go/no go gates to the programs with specific requirements would enable the review team to track progress and add resources as needed or stop programs that are not progressing at opportune times. This would also allow the creation of alternative approaches if deemed necessary or appropriate. The reviewer thinks that overall this process has been modified enough that it is meeting the needs of program area.

Reviewer 5:
The reviewer had no additional recommendations other than what was mentioned in questions 13 and 14.

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	Burress, Tim (ORNL)	3-17	3.63	3.44	3.44	3.56	3.50
DREAM (Development of Radically Enhanced Alnico Magnets)	Anderson, Iver (Ames)	3-22	3.67	3.25	3.67	3.50	3.44
North American Electric Traction Drive Supply Chain Analysis: Focus on Motors	Whaling, Christopher (Synthesis Partners)	3-26	3.10	2.70	3.60	3.20	2.98
Next-Generation Inverter	Zhao, Zilai (General Motors)	3-30	3.38	3.25	3.19	3.38	3.29
Unique Lanthide-Free Motor Construction	Gilbert, Alan (UQM Technologies, Inc.)	3-34	3.25	3.25	3.50	3.25	3.28
Alternative High-Performance Motors with Non-Rare Earth Materials	El-Refaie, Ayman (General Electric)	3-38	3.38	3.38	3.38	3.13	3.34
Advanced Packaging Technologies and Designs	Liang, Zhenxian (ORNL)	3-42	3.07	3.00	3.07	2.93	3.02

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Electric Drive Inverter Research and Development	Chinthavali, Madhu (ORNL)	3-47	3.50	3.14	3.21	3.21	3.25
Innovative Technologies for Converters and Chargers	Su, Gui-Jia (ORNL)	3-51	3.50	3.33	3.42	3.17	3.36
Advanced Low-Cost SiC and GaN Wide Bandgap Inverters for Under-the-Hood Electric Vehicle Traction Drives	Olejniczak, Kraig (APEI Inc.)	3-55	3.25	3.33	3.25	3.08	3.27
High-Temperature DC Bus Capacitors Cost Reduction and Performance Improvements	Yializis, Angelo (Sigma Technologies International)	3-58	3.58	3.50	3.50	3.33	3.50
High-Performance DC Bus Film Capacitor	Tan, Dan (General Electric)	3-63	3.08	3.08	3.08	3.25	3.10
Cost-Effective Fabrication of High-Temperature Ceramic Capacitors for Power Inverters	Balachandran, Balu (ANL)	3-68	3.50	3.40	3.40	3.20	3.40
Non-Rare Earth Motor Development	Burress, Tim (ORNL)	3-71	3.30	3.10	3.10	3.30	3.18
Performance and Reliability of Bonded Interfaces for High-Temperature Packaging	DeVoto, Doug (NREL)	3-76	3.42	3.17	3.42	3.33	3.28

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Electric Motor Thermal Management Research and Development	Bennion, Kevin (NREL)	3-79	3.29	3.29	3.43	3.50	3.33
Brushless and Permanent Magnet Free Wound Field Synchronous Motor (WFSM)	Ludois, David (U of Wisconsin-Madison)	3-83	3.42	3.58	3.25	3.33	3.47
Traction Drive Systems with Integrated Wireless Charging	Su, Gui-Jia (ORNL)	3-88	2.83	2.67	2.83	3.33	2.81
High-Efficiency High-Density GaN-Based 6.6 kW Bidirectional On-Board Charger for PEVs	Zhu, Charles (Delta Products Corporation)	3-91	3.38	3.25	3.13	3.50	3.30
Gate Driver Optimization for WBG Applications	Ericson, Nance (ORNL)	3-94	3.38	3.38	3.13	3.38	3.34
Power Electronics Thermal Management Research and Development	Bennion, Kevin (NREL)	3-97	3.50	3.33	3.17	3.50	3.38
Thermal Performance Benchmarking †	Moreno, Gilbert (NREL)	3-100	3.20	3.00	3.10	3.20	3.09
Multi-Speed Range Electric Motor Research and Development †	Tang, Lixin (ORNL)	3-103	3.00	2.90	2.30	3.20	2.89

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
30 kW Modular DC-DC System using Superjunction MOSFETs †	Erickson, Robert (U of Colorado)	3-107	3.42	3.33	3.00	3.25	3.30
Evaluation of an APEI 88 kW SiC Inverter with Next-Generation Cree 900 V SiC MOSFET Technology for Ford Automotive Systems †	Casady, Jeffrey (Cree)	3-110	3.17	3.08	3.00	3.17	3.10
Overall Average			**3.33**	**3.21**	**3.22**	**3.29**	**3.25**

Note: † denotes poster presentation.

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

Presenter

Tim Burress, Oak Ridge National Laboratory.

Reviewer Sample Size

A total of eight reviewers evaluated this project.

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

Reviewer 1:

The reviewer said that the approach of tearing down and benchmarking the various traction systems over the years has proved to be very effective and valuable. Many experts in the field really appreciate the various reports that come out of this effort. The reviewer noted that it provides experts with good understanding of the state-of-the art as well as a good basis of comparison of the various systems.

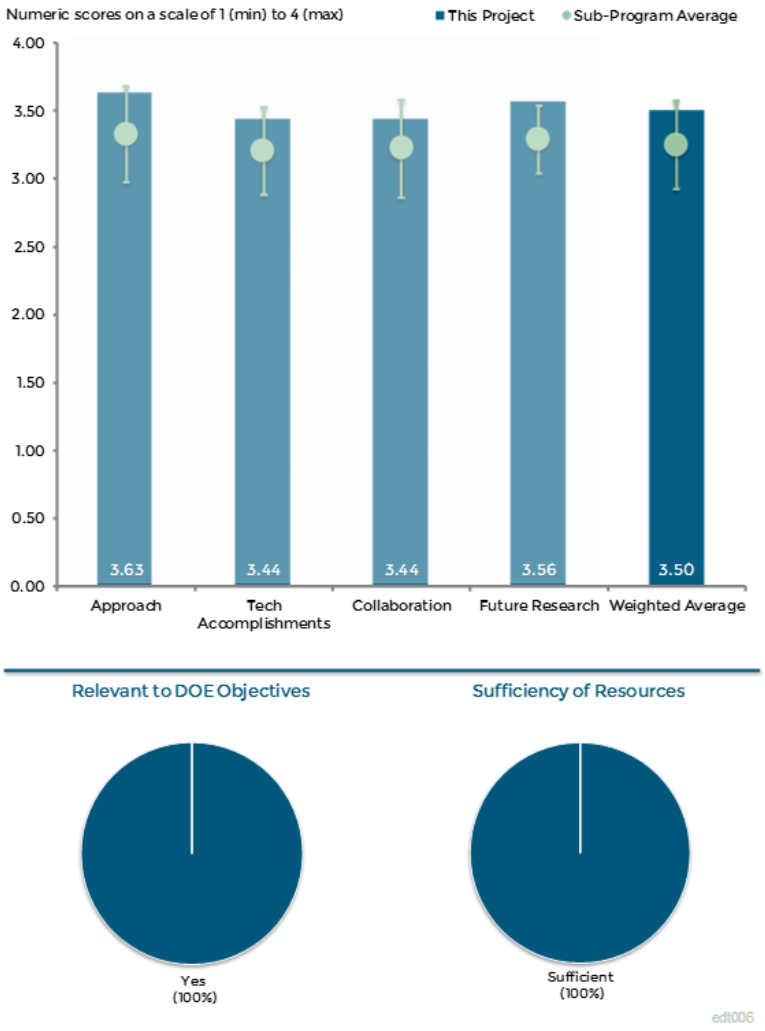

Figure 3-1 Benchmarking EV and HEV Technologies: Tim Burress (Oak Ridge National Laboratory) – Electric Drive Technologies

Reviewer 2:

The reviewer observed that this has been one of the most popular projects in the Annual Merit Review (AMR) meeting every year.

Reviewer 3:

The reviewer considered this ongoing program to be very helpful to research & development (R&D) in the United States, providing a relatively inexpensive way to educate all of us on what the competition is doing. The reviewer noted that there is necessarily some time lag in getting this information, so believed that it was good that the team was attempting to be as up-to-date as possible.

Reviewer 4:

The reviewer stated that this project aids development and verification of Department of Energy (DOE) 2020 targets. Thorough examinations of state of the art vehicle equipment provide specific goals for electric drive research efforts.

Reviewer 5:

The reviewer believed that the approach taken provides a very reasonable path to determining the state of the art for production electric drive systems for vehicles. The teardown and test results provide data that supports a thorough understanding of the evaluated system. This information enables a valid conclusion as the benefits of

the approach for this particular implementation and its usefulness in other applications. The reviewer believed that the comparison chart for the various systems that have been evaluated using this approach was very informative. Based on the chart, the second and third generation systems with higher power levels are approaching the 2020 DOE targets. This person concluded that the tasks and timeline are appropriate for the stated objectives.

Reviewer 6:

The reviewer stated that the tear down work is great as always, but would have liked to see an improvement on how the data is presented. This person thought a visualization of the outcomes, current and past, would have spoken volumes to ongoing trends, weaknesses, progress, etc. The reviewer suggested that the presenters need to move beyond Excel tables.

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

Reviewer 1:

The reviewer thought that the number of systems that had been benchmarked so far was impressive, and that the effort seemed to be fairly keeping up to date with the various traction systems that continue being rolled out.

Reviewer 2:

The reviewer appreciated the previous work on Toyota vehicles, which has been quite influential for the rest of us. This person found this year's emphasis on the 2014 Honda Accord and the upcoming BMW i3 to be very well directed.

The reviewer asked the project team to please be sure to include efficiency contours and detailed data for the boost converter in systems containing an intermediate direct current (DC) link, such as the Honda Accord. This is needed to complete the characterization of the system.

Reviewer 3:

The reviewer saw that the project's technical goals appeared to be on track, and thought that the work looks very good. One technical challenge is interfacing Oak Ridge National Laboratory’s (ORNL)'s control and test equipment with original equipment manufacturers (OEM) components. The group seems well equipped to deal with the issue and commence testing soon.

Reviewer 4:

The reviewer reported that the project has provided lots of information on current commercial hybrid electric vehicle (HEV) power electronics.

Reviewer 5:

The reviewer’s assessment of progress of this project was that it has been consistently excellent. The systems are obtained, examined, tested, torn down, and the results documented per the timeline. The teardown reports are thorough and provide insight into the design/performance goals of the supplier. The details provided from the teardown are useful and well documented. The reviewer noted, however, that the presentation did not provide an explanation as to why the boost converter switches were imbalanced: two on top versus three on the bottom, which would have been useful, and suggested including this in the final report. This person thought the presentation did a very good job of documenting the teardown of the components and the relationships between the components but lacked an overview of the system as installed in the vehicle. The use of a standard test procedure with specific operating points and known software provides an easy way to compare the different suppliers’ systems. The reviewer believes that this is a reasonable and efficient approach to test the hardware rather than try to use the system software from the supplier. In conclusion the reviewer was asked if there was any testing of the safety performance of the systems such as high-voltage (HV) discharge times, the use of high voltage interlocks, etc.

Reviewer 6:
The reviewer decided that good progress has been made thus far, but requested clarification on the capabilities ORNL offers that a major OEM could not do themselves.

Question 3: Proposed future research—the degree to which the project has effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways.

Reviewer 1:
The reviewer thought that the BMW i3 was an excellent choice for the next one.

Reviewer 2:
The reviewer agreed that examination of the BMW will be quite interesting as BMW is known to be very focused on this area.

Reviewer 3:
The reviewer saw good, diversified proposed future work targeting different vehicles and different components within the electric drive train.

Reviewer 4:
This reviewer estimated the work for fiscal rear (FY) 2015 to be on track. Several technical barriers were identified, but the team seems well equipped to address them and complete the project.

Reviewer 5:
The reviewer believed that the proposed tasks for the remainder of FY 2015 are appropriate to complete the benchmarking of traction systems of interest. This person was encouraged to see the addition of chargers to the teardown as this may have a larger impact on the creation or updating of standards. The reviewer concluded that the continued use of and improvement of the standard benchmarking is great.

Reviewer 6:
The reviewer said that future research seemed appropriate, but would have liked more time spent on the dissemination of data in a more transparent of graphical manner to better reveal the state of the art and its trends.

Reviewer 7:
The reviewer stated that the team may perform more technical tests on each component, though it may require more resources.

Question 4: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer praised that collaboration among the laboratories is outstanding. The information shared among the laboratories is an example of using the best resource for the task at hand with Argonne National Laboratory (ANL) providing vehicle performance data to ORNL to enable operating conditions to be set and ORNL providing component data to ANL for use in AUTONOMIE for more accurate simulations. AMES is the appropriate source for magnetic characterization. The reviewer concluded that this project may be used as the prime example of team collaboration.

Reviewer 2:
The reviewer found that the current degree of collaboration is appropriate for this topic.

Reviewer 3:
The reviewer commented the team has involved all the technical resources required to complete the project.

Reviewer 4:
The reviewer observed that most of the effort seems to be taking place within Oak Ridge National Laboratory (ORNL), which is okay because a good system and process have been established over the years.

Reviewer 5:
The reviewer said that the group works with several national laboratories and collaborates with John Deere on benchmarking areas. Additional industry partners could hasten the benchmarking process, though the reviewer realized this would come with many challenges (and perhaps has already been pursued).

Reviewer 6:
The reviewer said that it would be nice to see U.S.-based Tier 1 involvement for benchmarking, for instance, Magna Powertrain, Delphi, etc.

Reviewer 7:
The reviewer noted that although collaborator bullet items were included in the presentation, the level of participation from collaborators was unclear.

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

Reviewer 1:
The reviewer concluded that the project benchmarks the performance of highly relevant international efforts in the electric vehicle (EV) and HEV areas.

Reviewer 2:
The reviewer thought the project was very relevant and effective in identifying the state-of-the art and comparing it to the DOE targets.

Reviewer 3:
This reviewer reported that the project helps Tier 1 and Tier 2 suppliers understand details of system architecture, system performance, for future improvement of vehicles.

Reviewer 4:
The reviewer's assessment was that this work provides electric drive developers with hard technical targets for their respective systems. This hastens development cycles, allows smooth integration with existing and emerging systems, and eases the challenge of bringing energy efficient technologies to market.

Reviewer 5:
The reviewer believed that this project provides the critical benchmark information for other projects under the Vehicle Technologies Office (VTO).

Reviewer 6:
The reviewer considered benchmarking to be important to understand to state of the art production design and identify the gap for the future DOE target.

Reviewer 7:
This reviewer reported that this function is providing the status of the electric drive traction systems used in current production vehicles. This provides useable information regarding the remaining barriers and technology areas that require additional emphasis. This information can be used to identify research areas as well as prioritize them. Additionally, the reviewer stated that this task enables informal communication between industry and DOE regarding the goals and objectives of their programs.

Reviewer 8:
This reviewer thought that it does support goals, but indirectly, by providing a baseline for future innovations.

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

Reviewer 1:
This reviewer maintained that the results indicate that the task has sufficient resources in most cases as the reports are provided in a reasonable time – per the timeline. The reviewer inquired if the timeline was adequate and can more resources to support it could be justified. In general, the reviewer thought that the resources are okay, but having access to additional resources when required to support the typical issues may be justified. Based on the presentation, additional resources for assisting with the integration of the drive unit to the ORNL dynamometer and the control software may speed the evaluation up enough to allow faster reporting.

Reviewer 2:
The reviewer thought the resources were sufficient based on the level of effort.

Reviewer 3:
This reviewer agreed that the team had all the resources required to complete the project on a timely fashion.

Reviewer 4:
The resources seemed sufficient to this reviewer.

Reviewer 5:
The reviewer reported that this project appeared to have sufficient resources.

Reviewer 6:
The reviewer thought the scale of the effort appeared to be correct.

DREAM (Development of Radically Enhanced Alnico Magnets): Iver Anderson (Ames National Laboratory) - edt015

Presenter

Iver Anderson, Ames National Laboratory.

Reviewer Sample Size

A total of six reviewers evaluated this project.

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

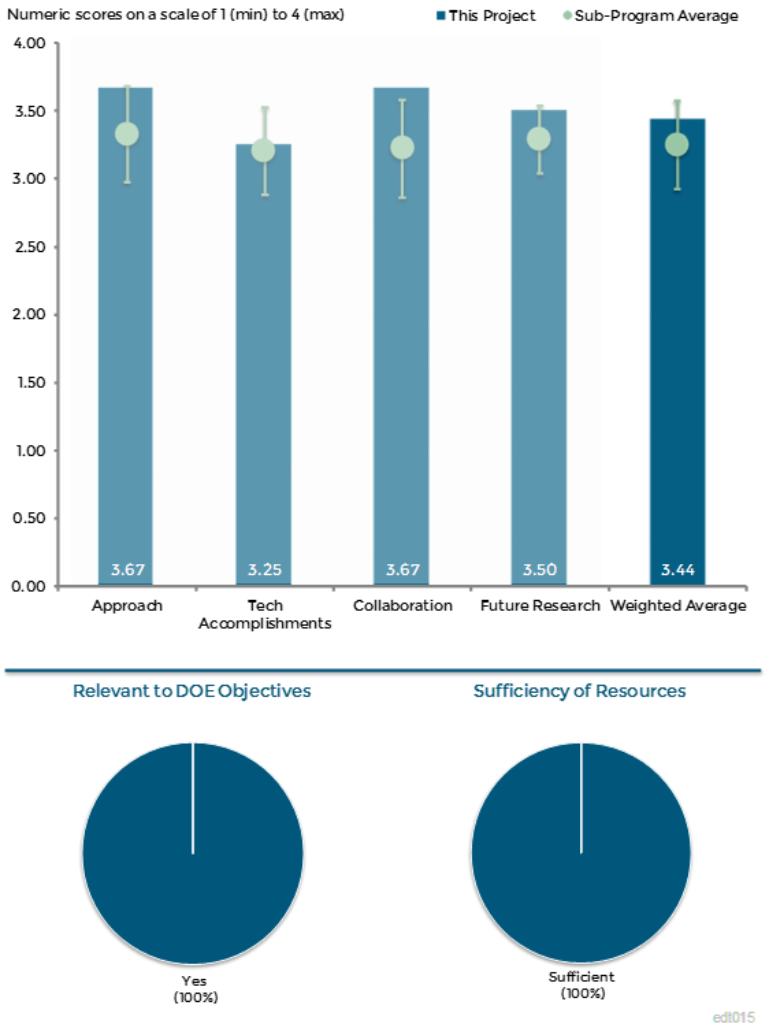

Figure 3-2 DREAM (Development of Radically Enhanced Alnico Magnets): Iver Anderson (Ames National Laboratory) - Electric Drive Technologies

Reviewer 1:

The reviewer reported that the project had great understanding at microstructure level by applying theory and experiment methods.

Reviewer 2:

The reviewer was excited to see if the team could achieve the very clear high level goals associated with an eventual motor application in this project. How these goals are translated to the specific activities within the program on magnet development appeared somewhat nebulous. The reviewer requested clarification on whether the current barrier to using aluminum/nickel/cobalt (AlNiCo) magnets is the Co content or the significantly lower energy density, and coercivity. The reviewer thought that it would be good to see a clear set of target metrics for this program, set prior to the go/no go decision point, and asked if the team can work with UQM to flowdown the minimum set of magnet properties needed for competitive performance compared to integrated permanent magnet (IPM) motors with rare earth (RE) permanent magnets (PM). General Electric (GE) appears to think even with the improved energy density, the motors do not compare well. This reviewer would be interested to see what advantages the current strengths of AlNiCo (e.g., very high temperature stability) provides to motors and assess if those aspects of the magnet properties should be focused on.

Reviewer 3:

The reviewer found the technical barriers to be quite well defined, and theoretical foundations to be sound, but that there seemed to be some lack of integration with other efforts, in terms of coordinating with absolute end users (e.g., automotive and aerospace industry), who could potentially benefit from the technology.

Reviewer 4:
The reviewer thought that the technical quality of the work is great, but that communicating a clear plan was not done well. The overall message of AlNiCo being viable was delivered, but sheer number of variables and options presented was excessive. The reviewer understood it is some basic research, but advised defining the AlNiCo research space/map and the multivariable thrusts being pursued to achieve performance boosts with more transparency. The reviewer counseled the project team spend more time laying out the map before getting into the weeds, so to speak.

Reviewer 5:
The reviewer determined the project had a very detailed approach to addressing the technical challenges, measurements, and processes to understand the metallurgical ways to improve the capability of AlNiCo magnets. There are several identified improvements in processing and chemistry to improve the magnetic properties of the AlNiCo 8 magnets. The reviewer suggested that integrating the improvements into a net capability be tracked. The reviewer found it hard to understand the overall progress from the briefing.

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

Reviewer 1:
The reviewer saw great efforts in improving coercivity of the AlNiCo magnet material. The coercivity of the AlNiCo magnet need to be improved to at least 4,500 Oersteds (Oe) at 150°C for it to be considered as a viable option in designing PM motors.

Reviewer 2:
The reviewer reported that work is about 19% complete, which is compatible with the total time span of the project. Although the desired focus at each year end has been indicated, this reviewer thought that a comparison chart or bar graph showing the desired milestone versus accomplishment would have been better to understand the status.

Reviewer 3:
The reviewer reduced the grade given this project because the progress towards the DOE goals is not being tracked as an aggregate. During the briefing, a target of 20 megaGauss Oersteds (MGOe) was mentioned. The reviewer suggested that this long term target or goal be captured and then broken down to define targets for each of the areas that have been, or are being studied. The reviewer provided the following path as a notional example, showing the path to 20, and proposed that it would look better on a graph MGOe on the vertical and time or other on the horizontal axis: starting point for AlNiCo 8 at 10 MGOe; MA anneal temperature for optimization of coercive field strength (HcJ) (Oe) from 800 to 1360 equal to 20% at 10.5 MGOe; drawing impact 1360-1845 equal to 26% at 11 MGOe; alloying optimization at 12; titanium optimization at 13; prolonged sintering at 14; copper precipitation at 15; magnetic annealing time optimization at 16; and undiscovered improvement required to get to 20 (super AlNiCo/other).

Reviewer 4:
The reviewer reported that the bulk of the work so far appeared to be on the reduction of cobalt, but that it was not clear what ideas were being pursued to improve the coercivity significantly beyond current state-of-the-art. The reviewer asked if it was the expectation of the team that the reduced cobalt content combined with improved processing to obtain better nanostructure will lead to the higher coercivity and energy density of 20 MGOe. Based on progress so far, the path to the higher energy density target is not clear to this reviewer.

Reviewer 5:
The reviewer saw lots of good work on the materials science end; however, the specific impact of each potential advancement in the material science should be summarized or at least attempted. This person advised that quantifying improvements towards the end goal.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer reported that many different organizations are referenced as contributing and the slides clearly provide credit where they are leading/contributing.

Reviewer 2:
The reviewer judged collaboration with the industrial partners and national laboratories to be adequate.

Reviewer 3:
The reviewer thought collaboration and coordination with various institutions (i.e., academia and industry), was excellent. This person advised that it would add more benefit if some coordination was also done with end users of the final product; automotive, aerospace, and other industries who use electric motors in a complete system.

Reviewer 4:
The reviewer deemed the collaboration with the motor developer that is working on an AlNiCo-based motor to be very strategic. This person proposed that the team consider tighter collaboration to perform trade-off studies on the different magnet properties – coercivity, energy density, high temperature performance, and mechanical properties – to establish the sweet spot for AlNiCo. It will also be good to have discussions with GE, the other team that has worked on AlNiCo motors, to reconcile any difference in opinion.

Reviewer 5:
Although collaborations are listed, this reviewer was not entirely sure how strong some of them were.

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

Reviewer 1:
The reviewer concluded that the project is well planned, but listed a few additional issues which would add benefit: first, 15 years' lifetime has been indicated for the magnets. It may be important also to think ahead about how to recycle those materials at the end of the lifetime; second, although comparison with different versions of the AlNiCo has been emphasized, a clear comparison between AlNiCo material developed in this project against RE materials also should be indicated more clearly, since after all, the intention is to replace the RE material. It has been indicated that the Go/No Go decision was based on a comparison between bulk sub-sized AlNiCo magnets against AlNiCo 8HE or 9. This comparison should be extended to RE magnets as well to better understand the complete picture; third, manufacturing process for high volume production should also be thought ahead, because eventually that will be necessary; and fourth, more detailed references on existing work such as patents and papers would be helpful.

Reviewer 2:
This reviewer would recommend slightly modifying the goal of the project from improving magnetic properties compared to AlNiCo 8HE and AlNiCo 9, to establishing minimum thresholds beyond which the material become a viable alternative to RE PM and trying to meet those. This may include a combination of trying to make up for the shortcomings of the material relative to RE magnets, and further improving on its strengths.

Reviewer 3:
The proposed future work will be very useful for advancing PM technology, but the reviewer would appreciate more quantification of the potential contributions of specific thrusts going forward.

Reviewer 4:
The reviewer would like to see the game plan that leads to 20 MGOe. Although the future work is good and great progress is being made, this reviewer would just like to see how the project team would get to the end goal.

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

Reviewer 1:
The reviewer submitted that a viable non-RE PM alternative would help in the penetration of electric or hybrid vehicles, which can lead to petroleum displacement.

Reviewer 2:
The reviewer believed that this work will make electric motors much more accessible for vehicle drive applications.

Reviewer 3:
Considering the volatility in price of the heavy RE material, this reviewer found that alternate options such AlNiCo provide cost effective solutions for the electric propulsion systems.

Reviewer 4:
The reviewer indicated that AlNiCo magnet manufacturing is capable of integrating the process and chemistry changes, so when the right solution is found, the time to get to the commercialized solution is short. The reviewer thought the cost of the vastly improved AlNiCo 8 magnets should be extremely competitive against rare-earth magnets, and not dependent on supply from China.

Reviewer 5:
This reviewer explained that in the mid- to long-term run it does, even though immediately it may not; because the project is about replacement of the existing motors which use RE materials, thus petroleum displacement may come about indirectly. If petroleum displacement in terms of vehicular fuel economy is considered, then it will not displace petroleum consumption. However, if the cost of getting RE material and its manufacturing process involve petroleum, then it may save fuel in an indirect manner.

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

Reviewer 1:
The reviewer saw that lots of great progress is being made, and asked the project team to please keep the focus on getting to 20 MGOe.

Reviewer 2:
The reviewer appraised the resources to be sufficient.

Reviewer 3:
The reviewer's assessment was that the resources indicated were reasonable.

North American Electric Traction Drive Supply Chain Analysis: Focus on Motors: Christopher Whaling (Synthesis Partners) - edt032

Presenter

Christopher Whaling, Synthesis Partners.

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.

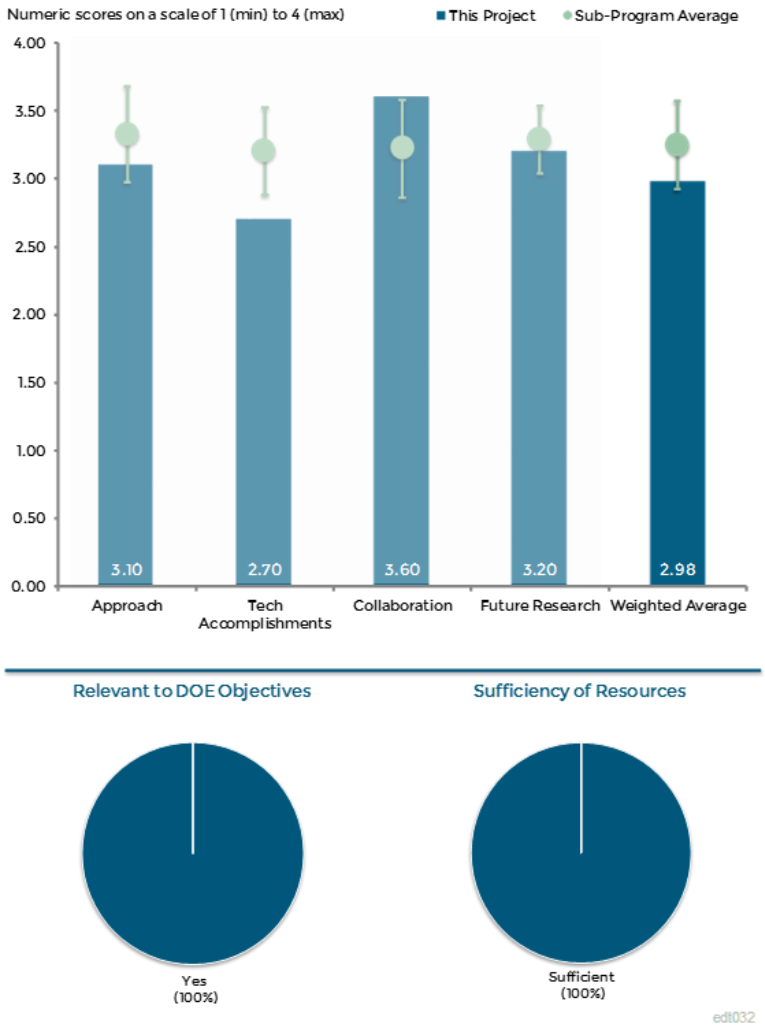

Figure 3-3 North American Electric Traction Drive Supply Chain Analysis: Focus on Motors: Christopher Whaling (Synthesis Partners) - Electric Drive Technologies

Reviewer 1:

The reviewer reported that the project appears to be well directed to assess the business state of North American EV efforts. Because results are preliminary and summarized at a very high level in the slides, they were difficult for this reviewer to assess at this intermediate point.

Reviewer 2:

The reviewer found good diversified approach in terms of the entities reached out to for interviews and information, but would have liked to see more in-depth interviews as well as a more expansive literature survey.

Reviewer 3:

The reviewer reported that the approach chosen was to collect, analyze, and report on data related to specific questions from DOE VTO, and concluded that this is a difficult task as the team needs to have a relationship with the suppliers based on trust to get any meaningful data. This person reflected that so far this has worked for this team on past surveys. Past presentations from this team have focused on inverters and related technology or components while this one focuses on motors. The reviewer liked the initial conclusions; even though they were preliminary, they still gave a sense of direction or status of current industry trends. The approach outlined on Slide 6 is well suited for this project.

Reviewer 4:

The reviewer thought that the study needed to be more comprehensive and provide actionable items.

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

Reviewer 1:
The reviewer considered these some illuminating preliminary statements of results.

Reviewer 2:
The reviewer thought that the number of in-depth interviews was reasonable for the timeframe reported. The reviewer said that it was nice to see preliminary conclusions understanding that they are preliminary, but that the results are too preliminary to judge progress related to motors. Based on prior project reviews, the project is about where this reviewer expected it to be.

Reviewer 3:
The reviewer reported some good high level observations about the market as well as some good information about the global markets, but suggested a more in depth understanding of the trends and needs of the North America market motors supply chain, and a better understanding of manufacturing cost breakdown, are both needed.

Reviewer 4:
The reviewer expressed that progress needed to be quicker for the information to be of use, and result in clear, actionable items that DOE can act on.

Reviewer 5:
The reviewer was of the opinion that more information was really needed, beyond the current calendar year (CY) 2010-2014 graphs and pie charts. There were a few leaders that stand out (i.e., Toyota, Tesla, BMW, and Nissan, etc.) that are leading the effort on EVs. While they are guarded with their information, it was not clear to this reviewer how the OEM and Tier 1 supply chain plans on addressing the carbon dioxide (CO2) emission restrictions by market: in the U.S. market, corporate average fuel economy (CAFE) standards require 54 miles per gallon (mpg) by 2025, which most OEMs say is impossible without electrification; in the Chinese market, second largest, the requirement is 60 mpg by 2025; and in the European Union (EU) market, third largest, CO2 restrictions by 2025.

It would seem to this reviewer that by 2018, automotive OEMs have to have a serious plan to address this pending challenge, or fight government regulators in their top three markets. Tesla and BMW seem poised to illustrate that the technology is there to hit these goals. The reviewer concluded that most of the market information appears to be looking backwards, where the top three market CO2 restrictions really have not had any bearing. Going forward, especially from 2018 onward, it seemed to this reviewer that this will be the key area of importance to judge EV adoption as the OEMs and government regulators are on a collision course.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer posited that the fact that there is data at all indicates that it is working well, because this project is based on collaboration. The reviewer believed that as the project team continues to build trust within the industry the results will continue.

Reviewer 2:
The reviewer ventured that the ability to establish a diversified network of experts for outreach is good, and that expanding this network can be even more effective.

Reviewer 3:
This reviewer wondered if, while OEMs are more guarded, it would seem Tier 1 suppliers would be more open.

Reviewer 4:
The reviewer reported that 100 research contacts were made, and 20 in-depth interviews contacted in the first quarter of 2015.

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 believed that continuing to reach out to experts is good, but even more important is vetting the findings so far.

Reviewer 2:
The reviewer determined that future plans are appropriate for this project, because the need to increase the data resource pool is key to a continued source of relevant information, which in turn will enable meaningful conclusions to be drawn, from which direction can be created. The reviewer agreed that getting involvement from the Electrical and Electronics Technical Team (EETT) is desirable.

Reviewer 3:
The reviewer reported that there was no slide on this, but assumed the work will continue in the same direction, and that more details will be presented in a report.

Reviewer 4:
This reviewer referred to previously mentioned ideas for future research.

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

Reviewer 1:
The reviewer postulated that EV adoption is key to reduce petroleum, and market information is needed to tell us when that will happen and what the market drivers will be. The reviewer wondered if this is the main market driver carbon dioxide (CO_2) restrictions.

Reviewer 2:
The reviewer believed that understanding the gaps in North America motors supply chain, and especially targeting traction motors, is very critical to being able to cut cost and establish a reliable North American supply chain for the HEV/EV space.

Reviewer 3:
The reviewer reported that this work assesses the reality and state of the North American business climate in plug-in/hybrid/electric vehicle (xEV) traction drives. The results are important to help guide the nation towards practical achievement of petroleum displacement through EV means.

Reviewer 4:
The reviewer stated that this project provides clear insight into what will make the program successful or not.

Reviewer 5:
The reviewer said that this project provides data that allows the capability of U.S. manufacturing to be determined, which will help determine what additional resources and projects will be needed to meet the DOE goals for US manufacturing of PHEVs.

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

Reviewer 1:
The reviewer thought the allocated resources were sufficient for the level of effort.

Reviewer 2:
The reviewer saw that funding appeared reasonable.

Reviewer 3:
Resources seemed to be sufficient to this reviewer, but was not sure if more would be better or if it would create trust issues.

Next-Generation Inverter: Zilai Zhao (General Motors) - edt040

Presenter

Zilai Zhao, General Motors.

Reviewer Sample Size

A total of eight 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 found that developing a concept or reference design to use as a baseline and have others evaluate it was a good approach, and allows for all parties to understand the tradeoffs and limitations of the design.

Reviewer 2:

This reviewer was generally supportive of this effort. The work being done is generally meso- and macro-scale packaging, which the reviewer considered an important near-term development topic that a company such as GM needs to pursue to address cost barriers. The reviewer regretted that few details were given in this presentation, but at least some of the results are given.

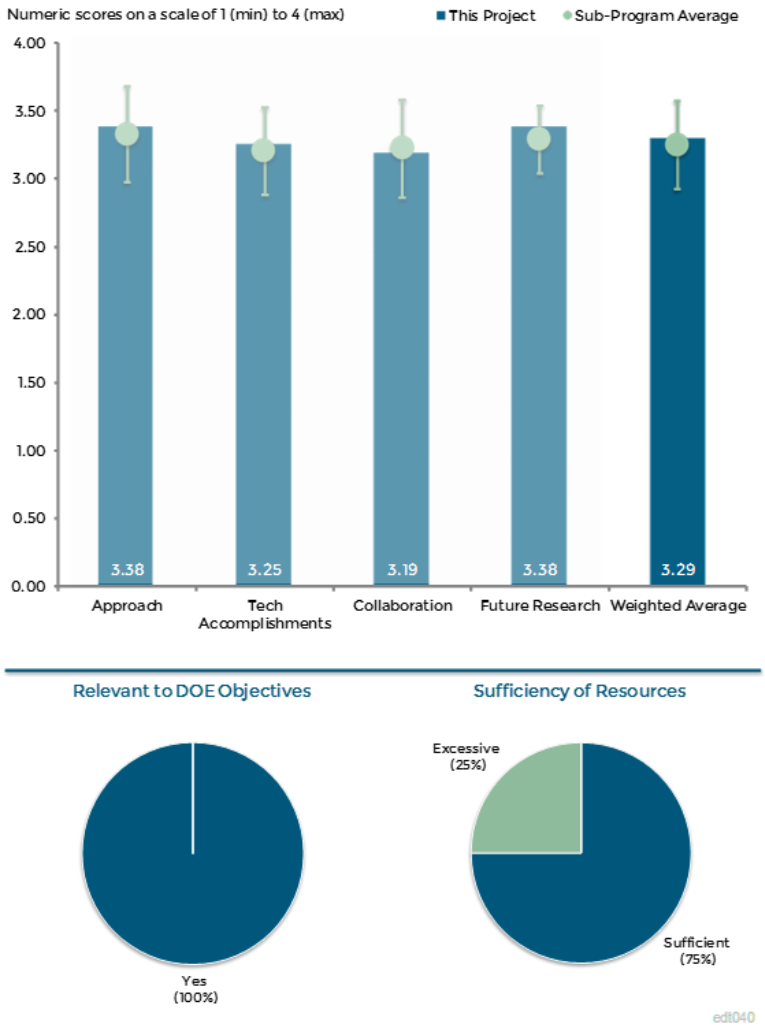

Figure 3-4 Next-Generation Inverter: Zilai Zhao (General Motors) - Electric Drive Technologies

Reviewer 3:

The reviewer concluded that the program goals are consistent with the DOE overall goals. However, this person wondered what the temperature requirements for the inverter are in this project, because it was not clear from the objectives or presentation. Also, the reviewer asked if this design is using current silicon (Si) device technology, and if so, how the timeline and output of the project fits with other DOE wide bandgap (WBG) inverter projects that are also ongoing.

Reviewer 4:

The reviewer stated that this project develops technologies and product design for low-cost high efficiency inverter capable of 30kW continuous and 55kW peak power. How cost and performance targets are met is missing from the report and presentation made during AMR.

Reviewer 5:

This reviewer reported that the technical approach was not evident in the presentation or material; however, it appeared that the key technical barriers were getting attention. The reviewer was not clear on what the path is/was.

Reviewer 6:
It was not very clear to the reviewer how the cost reduction can be achieved.

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

Reviewer 1:
The reviewer reported that the project has made progress on size and weight reduction, though there has been delay in milestones.

Reviewer 2:
This reviewer believed that the delay in the estimation of cost should be addressed. Specifically, it would be good to have a rolling estimate that can be updated and shared periodically. The presenter mentioned that the reduced cost is the primary benefit of this design given the same power density as current GM products; however, it was difficult for the reviewer to judge this cost merit without a firm estimate. Additionally, the reliability of the design was not fully clarified. In this reviewer's opinion, low cost is equally as important as high reliability.

Reviewer 3:
The reviewer reported that critical design review had been completed. Inductance of critical semiconductor/capacitor loop was reduced, although this person thought that others have solutions that are better. Substantial thought has been put into the overall assembly process, which the reviewer expected to reduce cost.

Reviewer 4:
The reviewer conveyed that the presentation covered numerous options for manufacturing processed development evaluated resulting in identification of refined manufacturing process, which is stated in the project report submitted for AMR 2015. Vertically integrated processes minimized loop inductance resulting is lower voltage overshoot during power semiconductor turn-off. Direct bonded copper (DBC) direct attach to the inverter cooling system resulting elimination of several thermal layers, hence reduction in the thermal resistance from junction to cooling systems. Integrated concept for the power stage is developed. The reviewer saw that details of electromagnetic interference (EMI) and electromagnetic compatibility (EMC) management method are missing. The reviewer recommended that peak load testing under extreme operating conditions should be evaluated, and that life and reliability of the inverter should be evaluated and determined.

Reviewer 5:
The reviewer sees the focus on manufacturing to reduce cost as a good sign. This person noticed that press-fit pins are being used and although the presenter commented on the pins there were not any comments about the sockets the pins interface with respect to the capacitors. The reviewer asked the project team to comment on the test plan used to evaluate the inverter.

Reviewer 6:
The reviewer observed that progress has been made in a few key areas, such as assembly process and loop inductance, but that it seemed that one of the keys to this configuration is attachment of DBC. This person was not sure this is adequately resolved yet, and was also a little disappointed in the delay of one year to provide production cost estimation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer remarked on the very strong, balanced team from the United States, Japan, and European Union.

Reviewer 2:
The reviewer observed a great team assembled under this project and thought that the OEM, several key Tier 1, 2, and 3 suppliers, and the key power electronics national laboratories were a fabulous slice through the industries. However, the actual contributions or involvement was unclear. The reviewer would like to know a little about what role the project team members play or how active the participation is for each.

Reviewer 3:
This reviewer stated that GM is working with a substantial number of suppliers and partners, as one would expect.

Reviewer 4:
The reviewer reported that ORNL and the National Renewable Energy Laboratory (NREL) are stated as collaborators

Reviewer 5:
The reviewer stated that there were many partners and collaborators.

Reviewer 6:
The reviewer believed the project had the power to collaborate with the entire supply chain.

Reviewer 7:
The reviewer thought the role of the collaboration partners was not clear at all from the presentation.

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

Reviewer 1:
The reviewer was definitely looking forward to the future evolution of this inverter, including the evaluation of WBG semiconductors, even if this will be done outside this program.

Reviewer 2:
The reviewer observed that key tasks are identified and are targeted towards relevant future activities in the project.

Reviewer 3:
The reviewer saw that they have a plan.

Reviewer 4:
The reviewer said that the remainder of 2015 work appears to be appropriate to the project. Again, it was difficult for this person to evaluate because of the limited data shown.

Reviewer 5:
The reviewer declared the team presented organized and logical next steps; now, just execute them.

Reviewer 6:
The reviewer referenced previously discussed cost and reliability assessment comments, and maintained that an initial cost and reliability assessment relative to the DOE targets would be beneficial to understand the potential benefit of this technology. In terms of extending this technology to WBG devices, there seemed to this person to be some challenges that would be imparted by the existing design. The reviewer asked how addressing these challenges would disrupt the overall architecture of the inverter.

Reviewer 7:
The reviewer opined that the project might have provided more information on the cost reduction target.

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

Reviewer 1:
The reviewer declared that moving advanced inverter technologies into production is a key benefit of the DOE activity, and this project supports that goal.

Reviewer 2:
Development of GM xEV technology could make a substantial and direct impact on petroleum consumption in the United States.

Reviewer 3:
The reviewer resolved that lowering the cost of electric-drive vehicles (EDV) power electronics helps to enable the market for EDV's which reduces our dependence on foreign oil.

Reviewer 4:
The reviewer thought that project work could meet DOE Advanced Power Electronics and Electric Motors (APEEM) targets, resulting in penetration and adoption of the power electronics into EVs everywhere.

Reviewer 5:
The reviewer said that cheaper and possibly more efficient power electronics are required for acceptance, and this project is written for just that.

Reviewer 6:
The reviewer pointed out that the project has been working on next generation vehicle power inverters with reduced size and weight.

Reviewer 7:
The reviewer related that a traction inverter is a key module in the xEV electrified power train system.

Reviewer 8:
The reviewer reported that the project took a ground-up look at a completely new inverter, valuing power density, efficiency, and ease of manufacturing steps. This person saw very thorough work in lowering the cost of this critical portion of EV drivetrains, and thought that future work evaluating WBG semiconductor and other packaging techniques will be important, even if done outside this program.

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

Reviewer 1:
The reviewer was very impressed with the amount of industry involvement from cost-share.

Reviewer 2:
Given the limited details presented, it was difficult for this reviewer to assess the value of the results relative to the DOE funds expended. On the other hand, two-thirds of the funds are GM cost share, and efforts in this area by GM are to be encouraged.

Reviewer 3:
The reviewer pointed out that the team is the largest automotive manufacturer.

Reviewer 4:
The reviewer thought that resources seemed sufficient in terms of the project cost, but hard to tell if it is resourced adequately at GM and the subs based upon the progress so far. It seemed to this person that this project is almost over yet there is still lots more work to do.

Unique Lanthide-Free Motor Construction: Alan Gilbert (UQM Technologies, Inc.) - edt044

Presenter

Josh Ley, UQM Technologies, Inc.

Reviewer Sample Size

A total of four reviewers evaluated this project.

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

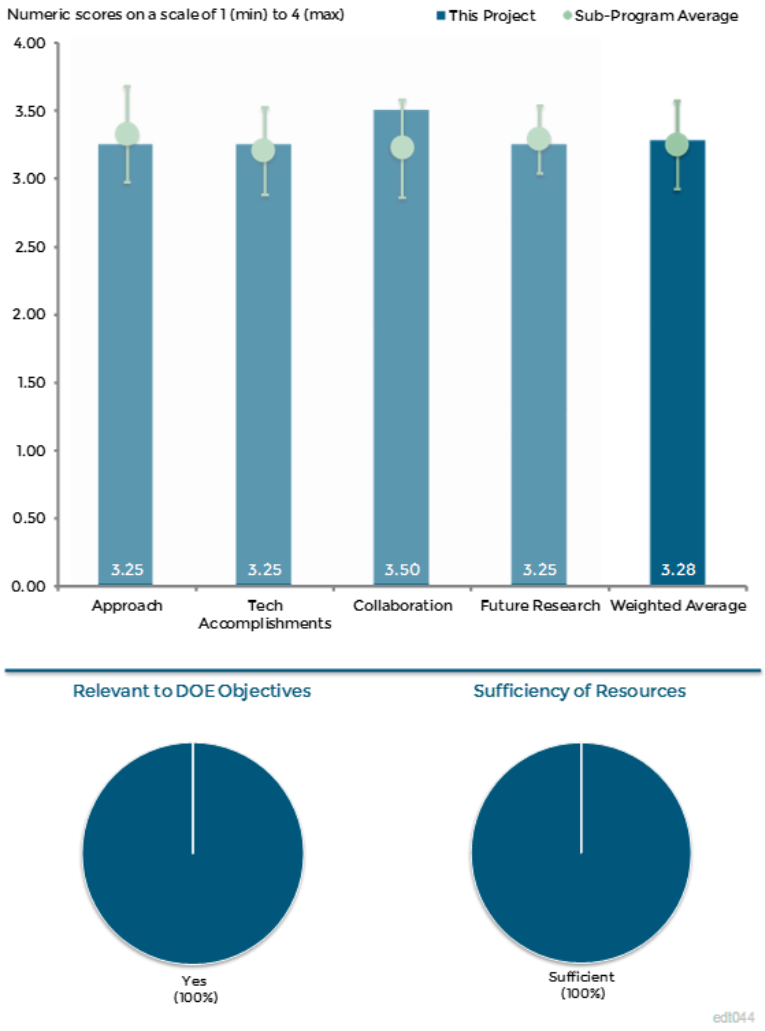

Figure 3-5 Unique Lanthide-Free Motor Construction: Alan Gilbert (UQM Technologies, Inc.) - Electric Drive Technologies

Reviewer 1:

The reviewer thought that the technical barriers are well defined in general. Integration with other efforts have been indicated explicitly in terms of automotive industry applications, which could potentially benefit from the technology.

Reviewer 2:

The reviewer declared that given the results achieved to date, the project is on an excellent path. However, further project progress is dependent on Ames Laboratory (AMES) delivering improved AlNiCo 8 magnets to improve the motor's top speed and torque capability. If the magnetic material is challenged for arrival, the project will suffer significantly. This reviewer emphatically praised Ames.

The reviewer went on to say, regarding the technology, that the surface mounting scheme that does not require much or any back iron is ideal for integrated starter motor generators (ISMGs) for parallel hybrid systems. The relative hollowness of the design enables packaging of the rotor around torque converters and clutches, or other components. This reviewer found that the challenge to address this market is to get the coolant temperature requirement closer to the 105°C capability, and suggested that a next phase for the project to work on increasing the temperature rating.

Reviewer 3:

The reviewer determined that, while the overall goals of the program are sound, the technical requirements for the motor appear to be too light relative to the many interrelated constraints being addressed by other teams, including elevated coolant temperature, tight system costs, etc. The reviewer stated that the summary statement by the team that the POC motor demonstrates performance very close to requirements with OTS magnet material may be accurate for the narrowly defined specs, but given the relaxed specifications (e.g., coolant temperature and transient conditions the motor needs to ride through), there may be room for improvement. It appeared to this person that for the AlNiCo properties available, the motor is just barely able to operate at

steady state conditions, and it was not clear it can survive fault conditions without significant demagnetization. The reviewer recommended that the team should discuss with DOE or NREL to obtain reasonable specs on transient performance.

Reviewer 4:

The reviewer believed that the key to using AlNiCo is in how to design rotor structure, but conveyed that the presentation did not talk about it at all for the reviewer to adequately rate the design and its success in the real world.

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

Reviewer 1:

The reviewer declared that the technical accomplishments for the first generation are excellent - a scorecard was provided, which was helpful. However, the reviewer pointed out that the first DOE requirement of greater than 90% efficiency was only reported as Analyzed, Comply, and that all other key DOE requirements had some discussion and data. This person suggested that an efficiency map be added or provided that shows efficiency as a function of speed and power or speed and torque.

The reviewer went on to say that NREL has the contract scope element of cost, but there was no data provided that discusses the design impact on overall cost. The person suggested that cost be a key element to be discussed. Mentioned within the briefing was that the current design magnetic material is not reduced due to the volume. Again, the reviewer indicated that the AMES project has the potential to significantly impact by providing a more power dense low cost magnet.

Reviewer 2:

The reviewer reported that work is about 80% complete, which is compatible with the total time span of the project. Although desired focus at each year end has been indicated clearly on items so far completed, from November 2014 until now, the accomplishment has not been clearly mentioned.

Reviewer 3:

The reviewer was of the opinion that the experiment results shared of POC one and two were marginally meeting the set goals by DOE. More details on the experiment results will be great to evaluate the design and its performance for the next time.

Reviewer 4:

The reviewer thought the design appeared to be at the hairy edge of demagnetization even under steady state load, the effect of armature reaction could be significantly higher under fault conditions (e.g., terminal short circuits), and needs to be studied rigorously.

This reviewer reported that the rotor design was not discussed in detail, but verbal comments suggested it is mostly air-core with the magnetic flux primarily going through the permanent magnets themselves. One would expect this to result in low armature reactance fields, but also very low reactances, on the order of 0.1 per unit (p.u.), and high short circuit currents, which would magnify the above problems. The reviewer asked the project team to please analyze this in detail.

Also, the reviewer pointed out that while the approach eliminates RE PM and may mitigate RE availability risks, it is not clear that the current design, with three times the amount of magnets, is a viable commercial alternative.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that all partners have clearly defined roles and contribute well to the overall value of the project.

Reviewer 2:
The reviewer sensed that the team is leveraging capability at the national laboratories very well, but suggested that there may be opportunity to reach out to other organizations to study impact of a more comprehensive set of specifications, including the potential for magnet demagnetization under fault conditions.

Reviewer 3:
The reviewer saw that collaboration and coordination with various institutions are only with government laboratories, and that there seemed to be lack of collaboration with academia and other industry. This person thought that it would add more benefit if some coordination was also done with end users of the final product such as automotive, aerospace, and other industries who use electric motors in a complete system.

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

Reviewer 1:
The reviewer related that future work has been clearly indicated, but suggested a few additional issues which will add benefit. First, comparison between AlNiCo materials developed in this project against RE materials also should be indicated more clearly, because after all, the intention is to replace the RE material. Second, manufacturing process for high volume production should also be thought ahead, because eventually that will be necessary. Third, the cost issue has not been clearly indicated. Finally, more detailed references such as patents and papers on existing work would be helpful.

Reviewer 2:
The reviewer said that because the impact of inferior permanent magnet properties is one of the largest risks, the plan laid out would make the most sense if representative magnets are utilized in the motor construction. This reviewer recommended the team wait for improved AlNiCo to perform a more relevant demonstration.

Reviewer 3:
The reviewer concluded that the critical barrier for the project is for AMES to deliver the 30% (or more) improved AlNiCo 8 magnetic material capable of integration into a motor. Based on review of AMES project edt015, it seemed very likely to this reviewer that the improved magnetic material will be provided.

Reviewer 4:
The reviewer recommended that future work should also include direct comparison of equivalent AlNiCo and NdFeB PM motors for performance, cost and manufacturability.

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

Reviewer 1:
The reviewer concluded that the project addresses the DOE goals of elimination of RE magnets, power density, and efficiency. An element that needs to be discussed further is how the project contributes to cost reduction.

Reviewer 2:
The reviewer thought that, considering the volatility in price of the heavy RE material, alternate option such AlNiCo provides cost effective solution for the electric propulsion systems.

Reviewer 3:
The reviewer determined that a motor that meets DOE requirements with AlNiCo magnets would mitigate the RE PM supply risks

Reviewer 4:
The reviewer thought that this project contributes indirectly, and in the mid- to long-term run it does. It may not directly influence the petroleum displacement, because it is about replacement of the existing motors which use rare earth materials. If petroleum displacement in terms of vehicular fuel economy is considered then it will not displace petroleum consumption. However, the reviewer deduced that if the cost of getting RE material and its manufacturing process involve petroleum, then it may save fuel in an indirect manner.

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 resources indicated were reasonable.

Reviewer 2:
The reviewer believed that based on the funding level, this project is sufficiently funded. Based on discussions during the briefing that John Lutz had passed away, the funding level may need to be revisited if his loss is requiring more than planned resources to be applied, in order to continue at the same rate.

Reviewer 3:
The reviewer said that UQM would be in a good position to determine if the resources are sufficient based on their extensive experience with similar projects.

Alternative High-Performance Motors with Non-Rare Earth Materials: Ayman El-Refaie (General Electric) - edt045

Presenter

Ayman El-Refaie, General Electric.

Reviewer Sample Size

A total of four reviewers evaluated this project.

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

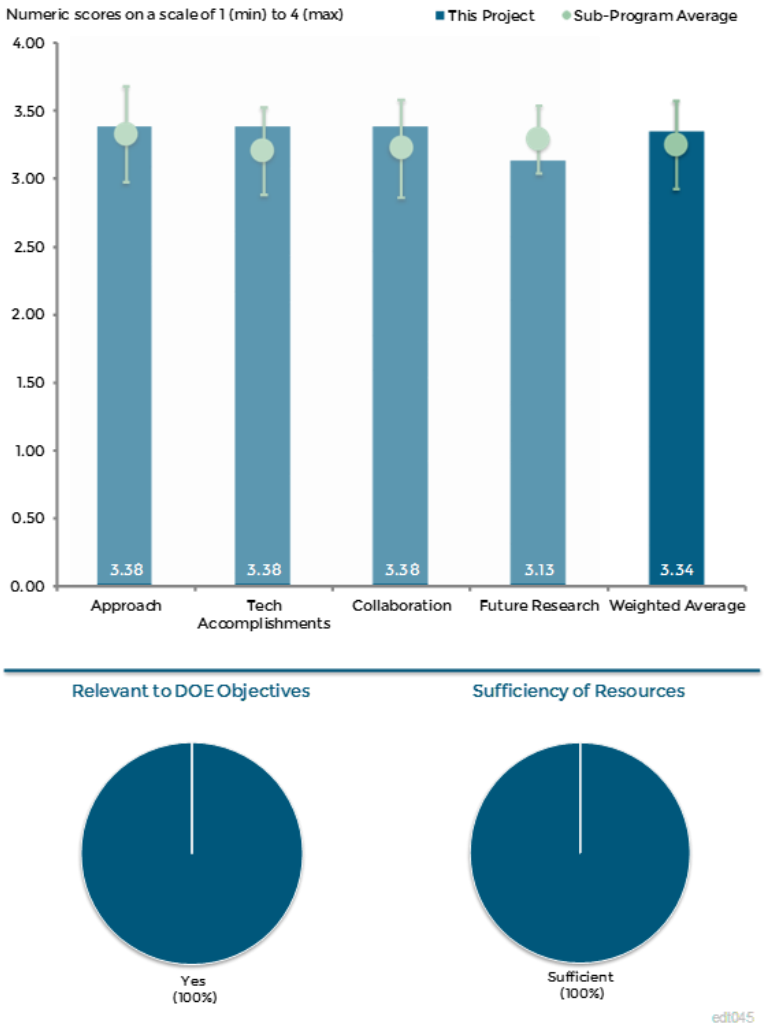

Figure 3-6 Alternative High-Performance Motors with Non-Rare Earth Materials: Ayman El-Refaie (General Electric) - Electric Drive Technologies

Reviewer 1:

The reviewer reported that this team is pursuing a very comprehensive search for machine topologies and enabling technologies to address the rare-earth permanent magnet challenge. While the reviewer thought this may be a good approach if sufficient resources are available, it would help to perform a down selection and focus on ideas with the greatest chance of making significant impact.

The reviewer expected that the team should be able to compare the motors being studied by computer modeling and analysis, because they are extensions of known topologies. There will be uncertainties, but it will be good to select the one or two most promising machine type to proceed to hardware demonstration.

Reviewer 2:

The reviewer judged the technical barriers to be well defined and clearly itemized. Although partnership with other entities have been clearly indicated, integration with other similar efforts or leveraging other existing efforts were not so clear to this person.

Reviewer 3:

The reviewer relayed that GE's approach to performing the work is to evaluate at least 10 different motor topologies that have the potential of meeting the DOE goals for motor performance without the use of RE magnets. Where conventional technology will not support meeting the performance requirement, GE is, in some cases, developing capabilities that make the motor topology possible, such as dual phase magnetic material and higher temperature insulation materials.

The reviewer thought that, where 10 topologies were evaluated, it would have been good to see the breakdown of how the different topologies performed and where they missed meeting the requirements.

Reviewer 4:
It seemed to this reviewer that GE's lack of OEM knowledge for the system optimization of HEV/EV applications may impact their ability to select the best design for such applications. The reviewer recommended that GE allow themselves some flexibility in the requirements, especially max speed and coolant temperature to see if this permits a better and/or cheaper motor 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 towards DOE goals.

Reviewer 1:
The reviewer reported that work is 78% complete, which seemed compatible with the total timespan of the project. Each year-end has been indicated clearly on items so far completed.

Reviewer 2:
The reviewer thought the new method for creating locally non-magnetic regions in motor laminations sounds interesting, though it could be quite a challenge to manufacture such laminations in mass production.

Reviewer 3:
It was clear to the reviewer that the team has done a very thorough work on both the motor and material development. However, this reviewer is wondering if the most effective path towards demonstrating the most promising technologies is being pursued.

This person asked for the team to please provide a summary of how the different motors stack-up against each other with an apples-to-apples comparison, with technical risks. While pieces of information were available throughout the presentation, it would help to have a table showing how the machines compare in terms of the key design specs. It was also not clear to this person what major risks were retired by the testing of the ferrite IPM motor. The electromagnetic performance is fairly well predicted with the sophisticated modeling tools available these days.

The reviewer concluded that if the team feels the dual phase material can be the most disruptive technology to come out this effort, it should allocate enough resources to try and scale this up and incorporate in a motor to demonstrate its benefits.

Reviewer 4:
The reviewer said the lack of a scorecard for motor topologies relative to the expressed targets makes it hard to evaluate the progress toward the goal, and recommended that a scorecard be provided for each relevant motor topology to understand how the motor performed relative to the goal. A one-page scorecard would work, and would make it clear why a particular topology was chosen.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer concluded that it was good to see the team pursuing broad collaboration across industry, academia, and national laboratories. This reviewer pointed out that one area for improvement may be collaboration within GE itself. It was not obvious from the presentations how much of this is taking place, but there may be value to finding traction motor applications within GE that have similar requirements as the DOE program and seek synergistic ways in which to demonstrate some of the disruptive non-rare earth (NRE) motor technology being developed.

Reviewer 2:
The reviewer reported that collaboration and coordination with various institutions have been very clearly indicated. It would add more benefit if some coordination was also done with end users other than the

institution of the principal investigator (PI), i.e. with end user of the final product e.g., automotive, aerospace, and other industries who use electric motors in a complete system.

Reviewer 3:

The reviewer expressed that the briefing and discussion does not make it clear on how the partners participated. For instance, there are three universities that have a role of evaluation of motor topologies, and it was not clear to the reviewer how the evaluations were completed. This person asked if their role for the evaluations was completed on physical motors, or if this was a modeling study. Further queries were expressed about whether all evaluated the same motors independently, or if the evaluation was completed as an integrated team. The reviewer stated that it is possible that this was a great story to be told but it is not easy to interpret based on the briefing materials and the briefing.

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 future work had been clearly indicated. A few additional issues that this reviewer expected will add benefit are as follows: One, manufacturing process for high volume production should also be thought ahead, because eventually that will be necessary. Two, the cost issue has not been very clearly indicated. Three, more detailed references such as patents and papers on existing work will be helpful.

Reviewer 2:

The reviewer reported that proposed work gets down to a final evaluation of motor topologies and choosing a path forward on one or more designs that have a high likelihood of meeting the performance and cost requirements. The scorecard will be a handy tool to provide the team with a clear picture to make the decision. The reviewer suggested that Slide 16, fourth bullet be changed to state finish the design for the final motor(s), because FY 2016 is the build and evaluation of the motors. Another option suggested was that a bullet be added to FY 2016 stating finishing the design before the build and test bullet.

Reviewer 3:

The reviewer realized that although it may not be easy to do at this stage in the program, the team should try to focus the program on the one or two key innovations with the greatest promise of impacting NRE motors. With information available to the team now, the team can try to separate the options that would make incremental advances from those that can be truly game-changing, and focus on those, e.g., the dual phase material for rotor laminations. The reviewer recommended that resources be allocated to do more work to understand the mechanical properties and manufacturing considerations.

Reviewer 4:

This reviewer proposed that when evaluating or selecting the best performing motor option, GE should describe the pros and cons of the inverter topologies for the different motor concepts as this could have an impact on the overall system cost.

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

Reviewer 1:

The reviewer reasoned that having low-cost, high-performance motors that are not dependent on volatile RE permanent magnets will add the stability to product costs that OEM's need. This person pointed out that this project also is developing technologies that are very innovative and could change or increase the options available to motor designers to maximize motor capability.

Reviewer 2:
The reviewer declared that all approaches being worked on have the potential to help reduce reliance on RE permanent magnet materials.

Reviewer 3:
The reviewer related that while this project may not directly influence the petroleum displacement, because it is about replacement of the existing motors which use RE materials. If petroleum displacement in terms of vehicular fuel economy is considered, then it will not displace petroleum consumption. However, this reviewer believed that if the cost of getting RE material and its manufacturing process involve petroleum, then it may save fuel in an indirect manner.

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 funding is approximately $2 million per year, and that there is a lot of motor topology evaluation and materials development. The reviewer considers this to be a good value for the funding available.

Reviewer 2:
This reviewer agreed that this is a well-funded project. However, it appeared to this person that the team is looking in many different directions, and that a better utilization of the resources may be obtained by focusing more narrowly.

Reviewer 3:
The reviewer said that resources indicated are sufficient, but that even though there is 50% cost sharing, possibly the project could be done at a lesser cost.

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

Presenter

Zhenxian Liang, Oak Ridge National Laboratory.

Reviewer Sample Size

A total of 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 found the project to be well designed and appeared to address several of the barriers, but was not sure that production cost was being considered. This person thought the concepts and prototypes were cool, but was not sure they could ever be commercially viable, and so suggested adding an OEM and/or a module or inverter Tier 1 supplier to the team might help keep this in check.

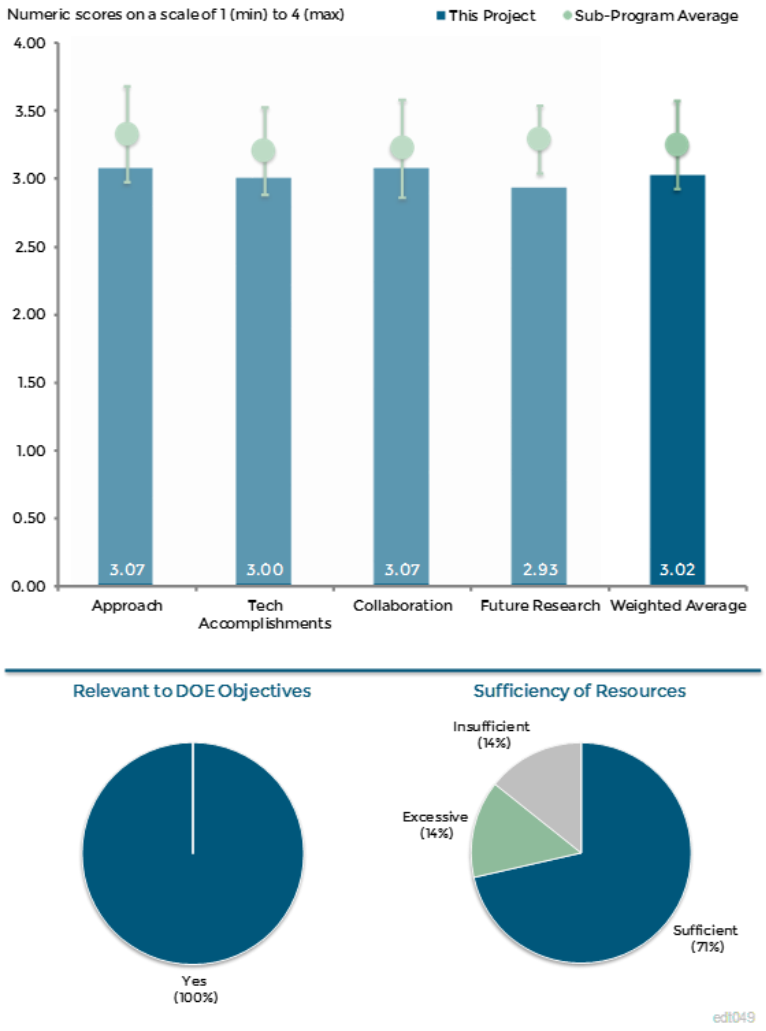

Figure 3-7 Advanced Packaging Technologies and Designs: Zhenxian Liang (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 2:

The reviewer considered the concept for a single package to be interesting, but the scalability of the design was not demonstrated in the current results. Regarding silver sintering, the evaluation of reliability of the bonding technique needs to be addressed, especially for high temperature operation. The reviewer believed that the emphasis on three-dimensional (3D) printing for the fluid manifold design seemed like a weak point for the current strategy, and suggested a simple polymer over-molding technique instead. This person concluded by asking how this approach isolates the coolant from the package itself.

Reviewer 3:

The reviewer saw generally sound work on packaging of WBG semiconductors, but also that the connection to overall system goals needs to be strengthened.

Reviewer 4:

The reviewer relayed that the approach addresses limitations of the state of the art (SOA) technology by replacing Si power devices with WBG devices by using innovative packaging techniques. Using the hierarchical packaging concept, a power converter's parts are integrated to obtain cost reductions, performance, and efficiency improvements. Comprehensive evaluation of the prototype converter shall be performed to assess functionality silicon carbon (SiC) multi-phase converter module.

The reviewer noted that the approach does not address EMI/EMC issues of the proposed power converter, as SiC inverters should have significantly increased value of dv/dt rate. The reviewer saw a need for thermal cycling and power cycling model of the SiC module to be developed. The coefficient of thermal expansion (CTE) mismatch between top layer of the SiC die and lead-frame (planar bonds) also need to be determined.

Reviewer 5:

It was not clear to the reviewer if the planar bond-all (PBA) package consisted of just a number WBG metal–oxide–semiconductor field-effect transistor (MOSFET)s and diodes, or if it was a requirement for the package that the thickness of the die be the same, or if dies of varying thickness could be accommodated.

Reviewer 6:

The reviewer found the approach of replacing Si devices with their SiC and gallium nitride (GaN) counterparts to promote their accelerated adoption in power conversion systems not to be compelling. This reviewer declared that surely the PI is aware that there are a number of companies working in this space already, such as Cree, Rohm, APEI, Powerex, USCi, etc., who already offer SiC power modules that are commercially available. However, the reviewer found the second bullet on Slide 6 to be a compelling reason, because it appears that the innovative power packaging technique offered up herein is the planar-bond-all (PBA) methodology. This reviewer will be interested to see how the PBA methodology truly differs from what has been presented before by packaging experts from around the world.

Slide 7 does not do much to unpack or unbundle the PBA methodology, and the renderings above the words Hierarchical Packaging are neither novel nor innovative. The rendering on the right, above Integrated Packaging shows a conceptual idea demonstrating multi-functional integration, building block, advanced manufacturability, and superior performance. The reviewer asked: what the functions of the multi-functional integration were; what characteristics made the building block a building block, how the building block was used, and how the building block could be used to build up a full inverter; what the advanced manufacturing techniques were; and how the results presented support the claim for superior performance.

The reviewer concluded that Slide 8 is reasonable for a proof of concept package prototype but possesses little resemblance to a sellable product.

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

Reviewer 1:

The reviewer believed that technical accomplishments were on track, and thought it was an impressive, albeit probably really expensive module.

Reviewer 2:

The reviewer thought development of the silver sintering bonding approach was interesting, but observed that issues related to reliability were not heavily addressed. The reviewer was left wondering how this was new relative to the current state-of-the-art in terms of the evolution of the bond structure at high temperature; for example, if voiding and electro-thermal migration of the bond line over time had been analyzed.

Reviewer 3:

The reviewer reported that hardware had been successfully produced, and results published. Improved performance is claimed, with metrics, but it was unclear to this reviewer what the baseline was or how this compares to the WBG packages of others.

Reviewer 4:

The reviewer relayed that SiC planar module packaging is completed, with double sided cooling. Electrical characterization of SiC planar module was completed, performance of the integrated cooling system was evaluated, and electrical reliability test setup of SiC power module was devised. Three-phase SiC module with

integrated thermal management was developed. Silver sintering technique was developed as part of SiC module development process.

This reviewer suggested that the PI develop cost of model of the process developed for doubled sided cooled SiC power module including a strategy how it could be scaled for mass production of the SiC power modules. The PI was also encouraged to identify U.S.-based source for equipment used in the module manufacturing processes.

Reviewer 5:

The reviewer determined that the start date shows 2015 but results shown go back into 2014, so this a continuation where the Si devices were replaced with SiC devices and a reliability test set up is proposed. This person asked the project team to quantify the parasitics, the thermal resistance and the manufacturability of this PBA approach.

Reviewer 6:

The reviewer said that Slide 9 shows a standard half-bridge configuration. It appeared to this reviewer that there are no Kelvin connections for either the upper or lower MOSFETs shown. These are required not optional. In the top-right rendering, it appears there are two gate connections with a single wire bond and a third bond pad that goes to the source of each MOSFET die in each switch position. It is labeled "E" here. The reviewer inquired about whether this represents insulated-gate bipolar transistors (IGBTs) versus MOSFETs and thus means emitter, or, whether this represents something else. The reviewer pointed out that one would expect to see many more wire bonds for the source/emitter connection to not only handle the 100 A of current but to minimize inductance.

The reviewer inquired about the following: reasoning for why the lower left schematic shows six terminals on the top left and right compared to the three in the PBA structure above and to the right of it; reasoning for why the jig has four power terminals (i.e., two on each side), but has only one terminal shown on the package on the right side; and reasoning for why the prototype PBA module in the bottom right has five pins and four pins, respectively, when compared to either the 6-6 on the lower left and the 3-3 on the upper right, because this is confusing.

Referring to the top-left picture on Slide 10, the reviewer asked why the bottom pin-fin baseplate is so much larger than the top pin fin, and questioned how one is to physically make electrical connections for V+, V-, and V midpoint. Looking at the top-right rendering, the reviewer inquired about which coolant fluid is to be used, and further emphasized that it appeared it must be a dielectric fluid. The reviewer also expressed interest in the finite element analysis (FEA) and computational fluid dynamics (CFD) results for these structures.

It was unclear how the values shown in the lumped parasitic element model (i.e., Slide 11) were obtained, and asserted that this should be revealed. The reviewer asked why the lumped parasitic element model was not used below in the LTspice electrical performance simulation. It appeared to be much more accurate then what is shown in the LTspice schematic. The reviewer highlighted that no detail is provided for the number and diameter of the wire bonds. The reviewer requested clarification on what the blue bar represents versus the red bar, how Lp is defined, and how Rp is defined because it is not obvious. The reviewer pointed out that there seems to be significant overshoot at the turn-on for the second pulse, and would like to know why.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

It seemed to the reviewer that the coordination between the partners was well-executed.

Reviewer 2:

The reviewer relayed that the PI has identified some key collaborators.

Reviewer 3:
The reviewer noted collaborations with suppliers and with NREL, but thought it would benefit this project to collaborate with industry that is producing packaged WBG modules.

Reviewer 4:
The reviewer felt that the collaboration that industry partners, such as U.S. DRIVE members, had with this project was vague, and who those partners are was not clear.

Reviewer 5:
The reviewer would have liked to see a vehicle OEM and/or a module or inverter Tier 1 on the team to keep an eye on commercial viability

Reviewer 6:
It was not obvious to this reviewer how all the partners have contributed to this work, specifically what UTK has done. The reviewer assumed that NREL was involved in the silver sintering development work, but was not clear on what was done by ORNL and what was done by NREL. The reviewer asked how industry contributed other than sourcing materials, specifically the contributions of Remtech, Masterbond, and U.S. DRIVE members.

The reviewer stressed that the Big Three automotive manufacturers focus on cost, cost, and cost, followed by reliability, and noted that, to date, this information is lacking in this work.

This reviewer affirms the decision by the ORNL team to include the NREL personnel for the thermal and reliability aspects to the project.

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

Reviewer 1:
The reviewer said that some key tasks were identified as part of future research.

Reviewer 2:
The reviewer thought that the items listed on the proposed future research slide are okay but somewhat vague.

Reviewer 3:
The reviewer asserted that greater emphasis should be placed on evaluating the reliability of the full package including the coolant flow through the manifold in contact with the package. Additionally, the reviewer recommended that the effect of high temperature operation on the silver sintered bond line be addressed.

Reviewer 4:
It was difficult for this reviewer to evaluate proposed future research. In this reviewer's opinion, developing high temperature materials, processes, and characterization of high-temperature SiC power modules cannot be done in one calendar year. Some material development work alone has taken 3-5 years.

Reviewer 5:
The reviewer asked for comments on the reliability tests to be performed; if they are targeted at an unpackaged inverter as shown, or just the PBA structure.

Reviewer 6:
The reviewer believed it would be nice to have a target vehicle to verify the designed inverter.

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

Reviewer 1:
The reviewer believed that this packaging of WBG semiconductor modules is needed to bring WBG technology into EVs. This would support displacement of petroleum use in transportation.

Reviewer 2:
The reviewer maintained that the use of SiC-based power electronics has the potential to save or recover significant losses incurred by the use of Si technology, and thus is a worthy technology to be funding.

Reviewer 3:
The reviewer believed that WBG power electronics know-how could be advanced through activities of this project.

Reviewer 4:
This reviewer agreed that lowering the cost of power electronics helps to enable the market for EDVs which reduces our dependence on foreign oil.

Reviewer 5:
The reviewer affirmed that WBG is a technology that has promise for petroleum displacement.

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

Reviewer 1:
There appeared to the reviewer to be a lot of work planned in this project and it was not clear that a $650,000 funded program would be sufficient. However, the reviewer also saw no evidence that the resources were not applied appropriately at this time

Reviewer 2:
It is not obvious to this reviewer that this new module has been tested beyond a double pulse test. Driving an electric machine for hours/days/weeks is a whole different beast. This project appears to have started in FY 2014. The period of performance appears to cut across four fiscal years from FY 2014 through FY 2017. This reviewer believed it is time to transition this concept to industry in order to bring it closer to reality – quicker.

Electric Drive Inverter Research and Development: Madhu Chinthavali (Oak Ridge National Laboratory) - edt053

Presenter

Madhu Chinthavali, Oak Ridge National Laboratory.

Reviewer Sample Size

A total of seven reviewers evaluated this project.

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

Reviewer 1:

The reviewer thought this was a very well designed and structured project, but added that more granularity in the FY 2015 timeline would be nice to see so that the project could be tracked with more fidelity.

Reviewer 2:

The reviewer believed that selecting a commercial power module and building an inverter around it is a good approach to establish a baseline, and that then building an inverter for comparison to the baseline was also a good idea. The reviewer asserted that it would be helpful to quantify results by creating a table, which could evolve, to show the comparison points to the baseline. Example data points could be die area, thermal resistance of the power device, fault monitors, switching frequency, etc., and comments could be added below as to how that could improve system cost or performance. The reviewer's idea of the comparison table would also apply to testing of WBG devices.

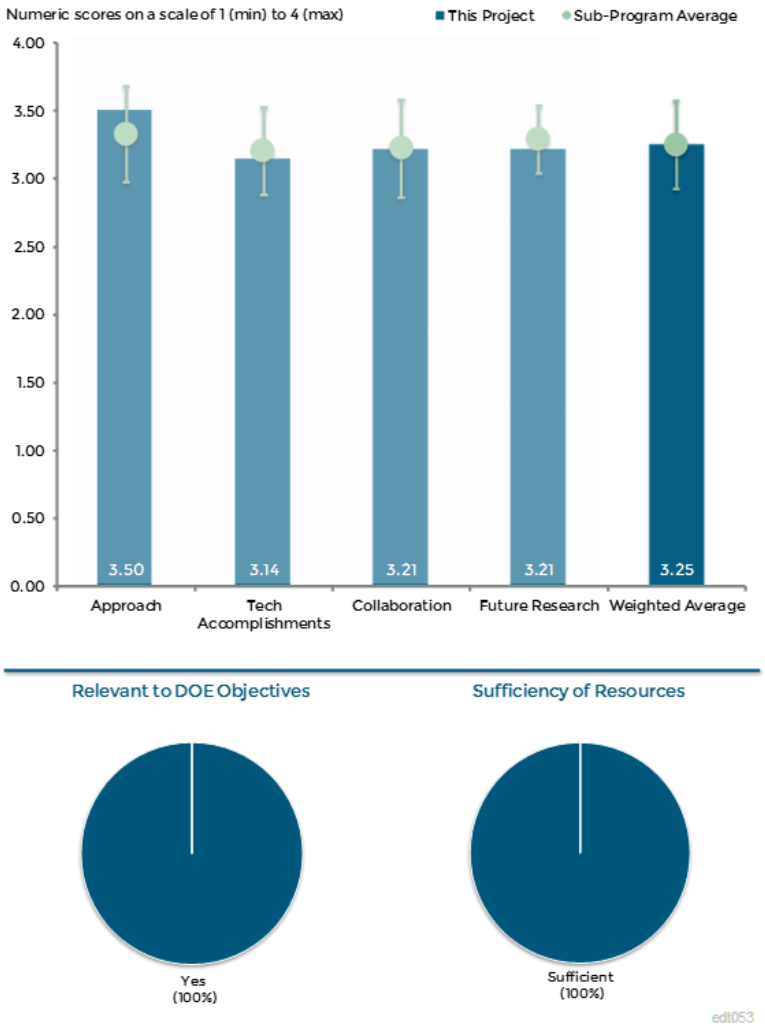

Figure 3-8 Electric Drive Inverter Research and Development: Madhu Chinthavali (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 3:

The reviewer thought that the air cooling approach for the 10 kilowatt (kW) size is attractive assuming the heat spreading is high, package thermal resistance is low, and the air volumetric flow rate is sufficient. The reviewer pointed out that excessive noise from the air flow and inverter size are also significant barriers, and the primary barriers to this approach. Separately, the 3D printing technology is an intriguing approach, despite the current high cost.

Reviewer 4:

The reviewer reported that the approach is to evaluate WBG devices and develop loss models. The steps involved are to build and test a 10kW air-cooled inverter; design, build, and test a 30 kW WBG-based liquid-cooled prototype; and, by year 3, build a 55 kW WBG inverter prototype at ORNL.

The reviewer encouraged the PI to take an approach that addresses issues with the production intent design. It this reviewer's view, it would be better service to industries if a 30 kW production design is fully completed with reference and application notes released in public knowledge space rather working on three different designs and not able to address practical issues of the production intent WBG power electronics.

Reviewer 5:
The reviewer stated that this project addresses pretty conventional topics, but does so in the context of WBG semiconductors.

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

Reviewer 1:
The reviewer stated that the project is just getting started but still has completed the foundational work needed to build upon later in the execution of the project. The reviewer applauded the use of 3D printing to quickly get air-cooled inverter built, and saw good progress on test and characterization of planar versus trench devices. This person would like to see more on bulk capacitor plans in this project, and also adequately addressed plans for switches, as the project also includes "reduce cost through novel interconnects." The reviewer did not see that covered in the presentation material.

Reviewer 2:
The reviewer observed a new start and that the plan has promise.

Reviewer 3:
The reviewer stated that so far, the results have dealt with a 10 kW air-cooled prototype, protection in a gate driver IC, and double pulse tests. Additionally, there has been 3D printing of parts of the 10 kW prototype, although the investigators have not identified what new performance is gained from this. The reviewer found that investigators need to more clearly identify what technical accomplishments distinguish this project.

Reviewer 4:
The reviewer reported that the volumetric power density for the air cooled inverter is low, as expected, and that this seemed to be the primary drawback to this approach. The reviewer asked what the volumetric power density benefit for the 3D printing approach was, because it was not fully clear. This person also wondered what specifically had been simplified with regard to electrical connections, packaging, cooling, etc.

Reviewer 5:
The reviewer reported that a 10 kW WBG inverter using ORNL SiC devices had been built and tested. Double-pulse set-up is developed. Static characteristics and switching losses of planar and trench SiC MOSFETs are compared. Protection functions of SiC MOSFET driver are demonstrated. 3D printed air-cooled inverter model is developed. This reviewer thought it would have better if an X-ray picture of module was taken after 100 hours testing and degradation of the power module assessed.

Reviewer 6:
The reviewer recommended the project team focus on the water cooled design, because it is hard to investigate both air cooled and water-cooled in one program.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that it looked like there is good inter-lab collaboration on this project.

Reviewer 2:
The reviewer thought the choice of partners was good.

Reviewer 3:
The reviewer imparted that there is collaboration with suppliers and with NREL.

Reviewer 4:
The reviewer saw collaborators for device prototype suppliers, customer capacitors suppliers, and thermal analysis support reported in report submitted for DOE-AMR 2015.

Reviewer 5:
The reviewer related that there was a good who's who of WBG device suppliers on the team and well as capacitor suppliers. It was not obvious to the reviewer what the cap suppliers are contributing, or who if anyone the project team is partnering with for interconnection of low voltage components.

Reviewer 6:
The reviewer said that the evaluation of SiC is becoming more complex as more suppliers and more parts are entering the market, and assumed that the trench-planar SiC MOSFET comparison was with one supplier. This reviewer would suggest in the future to include a summary for the power transistor by manufacturer, voltage, generation number, specific RDSON, EON, and EOFF.

The reviewer also wondered if there may be a better way to do this graphically, but both SiC users and SiC manufacturers could benefit from an independent, objective 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 decided the push towards higher-power inverters seems to mirror the industry needs. As shown by the Tesla model, the move to put higher-power EV or xEV vehicles in the premium category is a good way for advanced technology to penetrate automotive market until volumes and costs decrease. The reviewer revealed that there is a great deal of activity in the European Union market to respond to Tesla's challenge, with premium sports or luxury vehicles, with 100-300kW of power in the drivetrain. This reviewer concluded that WBG semiconductors should fit this need well.

Reviewer 2:
The reviewer thought the approach was a good start with a clear direction for the future, but wondered if the smart gate drive circuit in 2017 was coming from this project or another project.

Reviewer 3:
The reviewer decided that tasks and topics for future research seems appropriate; however, tasks and topics do not address problems faced by industries.

Reviewer 4:
The reviewer was not clear on decision points, but believed that the FY 2015-FY 2017 tasks are the logical progression of the project

Reviewer 5:
The reviewer was concerned about the size and air flow requirement for the proposed 55 kW air-cooled inverter proposal. This may be the primary limiter and need to be fully addressed.

Reviewer 6:
The reviewer pronounced that the investigators need to better make the case for what technical accomplishments could come out of this project that would distinguish it from others.

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

Reviewer 1:
Working on all aspects of lowering the cost, and increasing the power density, of the electric drive train. Power density and efficiency are improved through the use of advanced technologies in additive manufacturing, advanced packaging, and WBG semiconductors.

Reviewer 2:
The reviewer anticipated that 3D printing of electronics would be the future, so this seemed highly relevant, although maybe not for extremely high volume applications.

Reviewer 3:
The reviewer concluded that WBG inverter technology could aid in performance of EVs.

Reviewer 4:
The reviewer disclosed that the project aims to develop WBG power electronics know-how, but opined that it would be nice to release design application notes.

Reviewer 5:
The reviewer reasoned that improving the cost and performance of power electronics helps to enable the market for EDVs, thus reducing our dependence on foreign oil.

Reviewer 6:
The reviewer expected that big gains will come from the WBG portions of the project, but that commercial viability of three-terminal WBG in the DOE's planning horizon is questionable

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

Reviewer 1:
The reviewer thought it seemed to be resourced and funded appropriately.

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

Presenter

Gui-Jia Su, Oak Ridge National Laboratory.

Reviewer Sample Size

A total of 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 approach appeared to the reviewer to be versatile and applicable to a variety of vehicle architectures. The ability to charge the accessory battery is additionally a beneficial feature. The reviewer asked if there is a specific size target for the system.

Reviewer 2:

The reviewer described this as a well-designed technical approach that appeared feasible and is addressing issues.

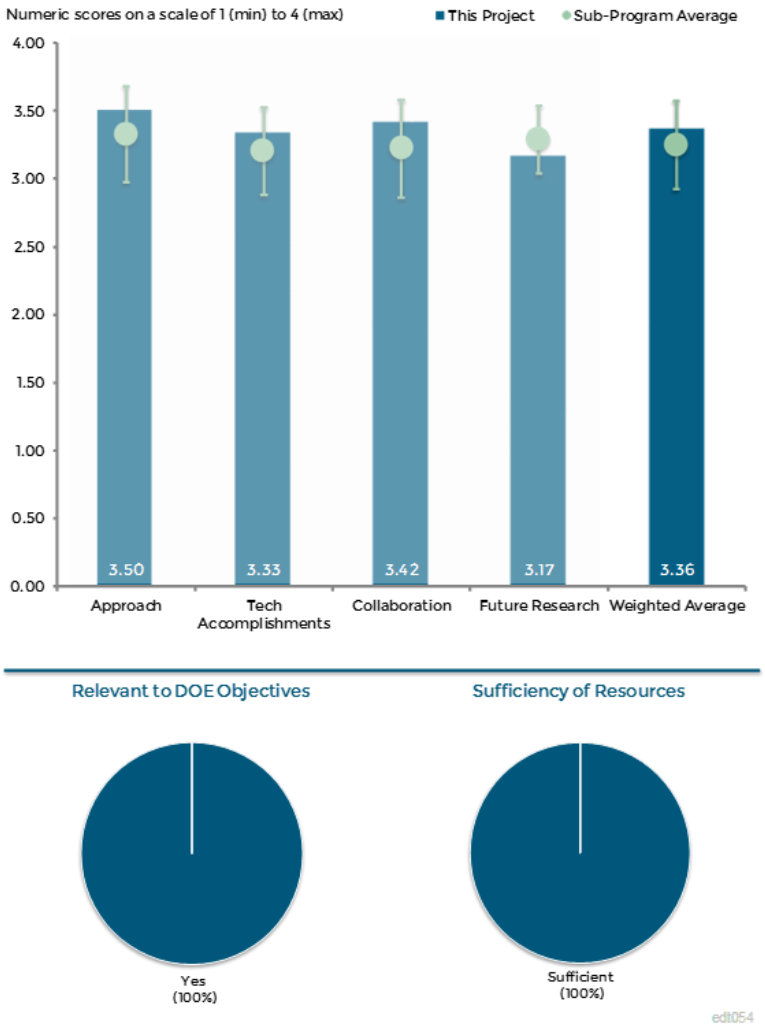

Figure 3-9 Innovative Technologies for Converters and Chargers: Gui-Jia Su (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 3:

The reviewer said this was one of several competing projects in this area. This project employs WBG MOSFETs, a dual-active bridge circuit for isolation and control, a 14 V charging output, integration with inverter and machine windings, and planar transformer.

Reviewer 4:

The reviewer thought that Slide 6 nicely summarized a reasonable approach to be used. The bottom figure portrays a 240/120 V input to the traction drive motors and SiC inverters. This AC input must be rectified so as to establish the input DC bus for the isolated DC-DC converter. The reviewer determined that Slide 7 implies that the traction drive acts as the on-board charger (OBC) alternating current (AC)-DC front end, but exactly how this will be done would be helpful to see. This person asked if the PI assumed an intervening DC-DC converter between the battery pack and the traction inverter input. The latter four attributes of the OBC are all important to demonstrate within this project.

In Slide 7, this reviewer believed that the use of planar magnetics for transformer Tr is a good direction to pursue for the all-WBG converter. The reviewer agrees that the dual active H-bridge is a most promising topology for the isolated DC-DC converter. The reviewer believes it is important to consider the spatial

distribution of the following subsystems: The 240/120 V source, the traction inverter, the interior permanent magnet synchronous motors (PMSMs), the WBG isolated DC-DC converter, the car's battery pack, and the 14 V battery for auxiliary loads. The parasitic resistance and inductance associated with cabling/bussing among these subsystems could be significant – thus having an impact – when integrating this approach into a PHEV.

Slide 8 states the flexibility of this solution to various traction drive system architectures. The reviewer thought it would be worthwhile to provide the circuit description for each. This reviewer also recommended that the Slide 9 goal of better than 96% should include an input filter between the 240/120 AC system and the rectifier; and similarly, it should include an output filter between the isolated DC-DC converter and the battery pack. The input filter could possibly be motor windings.

Reviewer 5:

The reviewer restated that the approach is to overcome the limitations of present semiconductor and magnetic materials with WBG devices and advanced magnetic materials. This is expected to increase power density, specific power and efficiency at lower cost, and to further reduce cost by using novel integrated topologies and control strategies. The adopted approach offers the following aspects: it could be useful in most traction drives; isolation converters can be applied standalone on OBC; developed converters have bi-directional power flow; and use of WBG devices enables high efficiency and high power-density.

The reviewer suspected that these claims may not be universally valid, for example, OBC uses electric machines in charging circuit and machine inductance varies over a wide range depending upon number of poles and types of electric machine used. High-pole count PM machines are getting very popular due to their smaller weight and size and they have much smaller leakage inductance than induction machines.

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

Reviewer 1:

The reviewer saw good progress to date, and reported that the topology, and WBG switches are progressing well. It is not clear to this reviewer what the real progress and plans are for magnetics although the right partners are there for this.

Reviewer 2:

The reviewer thought there were good preliminary results. Nano-magnetic powder material is an exotic transformer with possible long-term research implications.

The reviewer reminded the investigators that in the early designs that evolved into the GM EV-1, a charger used the machine windings as well. This eventually was abandoned because the common-mode currents caused by capacitance from machine windings to vehicle frame were excessive. The current approach employs additional means of isolation, so it is not clear what the implications will be regarding common-mode leakage during charging and the associated difficulty in meeting safety standards. The reviewer wondered if perhaps the investigators should consider this.

Reviewer 3:

The reviewer said the system appeared to have a high efficiency, but was concerned with the overall size of the system, and so recommended a focus on downsizing the package be considered in the future.

Reviewer 4:

The reviewer reported that Slides 11-13 demonstrate the high efficiency of the 6.6 kW SiC-based isolated DC-DC converter alone from FY 2014. This person asked what the continuous and peak rating of the SiC traction drive that was presented on Slide 14 was. The peak charger system efficiency was 96.5%. This appeared to the reviewer to be at nearly 4 kW of output power according to Slide 14 and Slide 15. This person would be interested to see documented efficiencies at 120 V AC input, instead of 240 V. The reviewer thought Slide 15

would have been better if the Si IGBT and MOSFET data points aligned with the SiC MOSFET data points so a true comparison could be made.

The reviewer asked if the AC/DC converter portion of the OBC had closed-loop control of the AC current with grid synchronization in Slide 16, if there was a closed loop DC-link voltage control, if it complied with EN 61000-3-2 limits, if the investigators had switched this block at 1 MHz or above, and why the 6.6 kW SiC AC-DC front end drops off so quickly at light loading. At an output power of ~1 kW, this reviewer would expect an efficiency greater than 97%, greater than 98% at 2 kW, etc.

The reviewer said Slide 18 shows preliminary results for a normally-on GaN device from IR/Delphi, and wondered what resistance was used to ensure stable switching in the Cascode configuration, since none is shown.

Reviewer 5:

The reviewer believed the prototype designs developed in this project do not address production issues. The reviewer restated that the 2 kW 14 V converter is built using ORNL packaged SiC switch based off Cree SiC MOSFETs. Planar magnetic is used, which offers improved thermal management; heavy copper pour printed circuit boards (PCBs) are used. Peak efficiency of 97.5% to 99% is obtained. Test results of 6.6kW SiC charger are demonstrated. 3.3kW GaN isolation converter design is competed and prototype hardware is tested. Aegis Technology is engaged in development of transformer core design for GaN based charger.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer exclaimed that there was a great team of partners and collaborators.

Reviewer 2:

It seemed to the reviewer that the collaborating partners are working well together, although this could have been better highlighted in the presentation.

Reviewer 3:

The reviewer judged the external collaborations to be appropriate, although it would be appropriate to collaborate with potential end users of this work.

Reviewer 4:

This reviewer's appraisal was that this is a solid team that should be capable of carrying out this effort. It appeared to this person that collaboration and coordination among the team members is present.

Reviewer 5:

The reviewer reported that Infineon, Delphi, RoHM, Aegis Technology, Hitachi/Metglas, Ferroxcube, and NREL are collaborators in this project as per the report the PI submitted for DOE-AMR 2015.

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

Reviewer 1:

The reviewer pronounced that the proposed remaining work is a logical continuation of this project.

Reviewer 2:

The plan seemed reasonable to this reviewer.

Reviewer 3:
The reviewer thought everything looked good on topology and WBG switches, but the magnetics approach and future work was not clear.

Reviewer 4:
The reviewer asked the investigators to please look into the size reduction of the system, specifically reducing the two-dimensional footprint, as this technology is transitioned/licensed to collaborative partners. This reviewer wondered if there were any EMI safety concerns for the placement of this system in the vehicle.

Reviewer 5:
The reviewer stated that 6.6 kW all GaN isolation converter build is suggested within project activities to take place during FY 2016. This will be followed by integration of 6.6 kW GaN converter with WBG traction drive. The PI also suggests that OBC shall be characterized. The reviewer reiterated that production issues were not addressed, such as EMI/EMC issues are missing from project tasks for the future research.

Reviewer 6:
This reviewer concluded that it would be nice to conduct EMI testing and see if it meets the charger requirements.

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

Reviewer 1:
A versatile and efficient onboard charger has significant potential for future electrified vehicles.

Reviewer 2:
The reviewer considered this project to contribute directly to the adoption of PHEVs and the reduction of GHG emissions via the use of WBG semiconductors to obtain increased efficiencies.

Reviewer 3:
The reviewer related that this advances WBG power electronics know-how and could support DOE-APEEM targets.

Reviewer 4:
The reviewer found that WBG, Novel topologies, and advances in magnetics are all needed to converge for a unified petroleum displacement strategy.

Reviewer 5:
The reviewer estimated that improved onboard charging is needed to enhance the general acceptance of EV and PHEV systems.

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

Reviewer 1:
The reviewer stated that this appears to be a three-year long project spanning FY 2014, FY 2015, and FY 2016. In the first two years, nearly $1.7 million was either spent or will be by 9/30/2015. This reviewer presumes that another estimated $850,000 is yet to come in FY 2016. Resources appear to be more than adequate for this work.

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

Presenter

Kraig Olejniczak, APEI, Inc.

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 reported that the project is looking both at SiC and GaN, with a focus on packaging and its performance which is desperately needed, but that it really left cost out of the equation.

Reviewer 2:

The reviewer decided the approach was logical and to the extent the technical barriers are addressable, and the project was well designed. At this point in the project, some of the feasibility is called into question, especially if the GaN portion of the program get there.

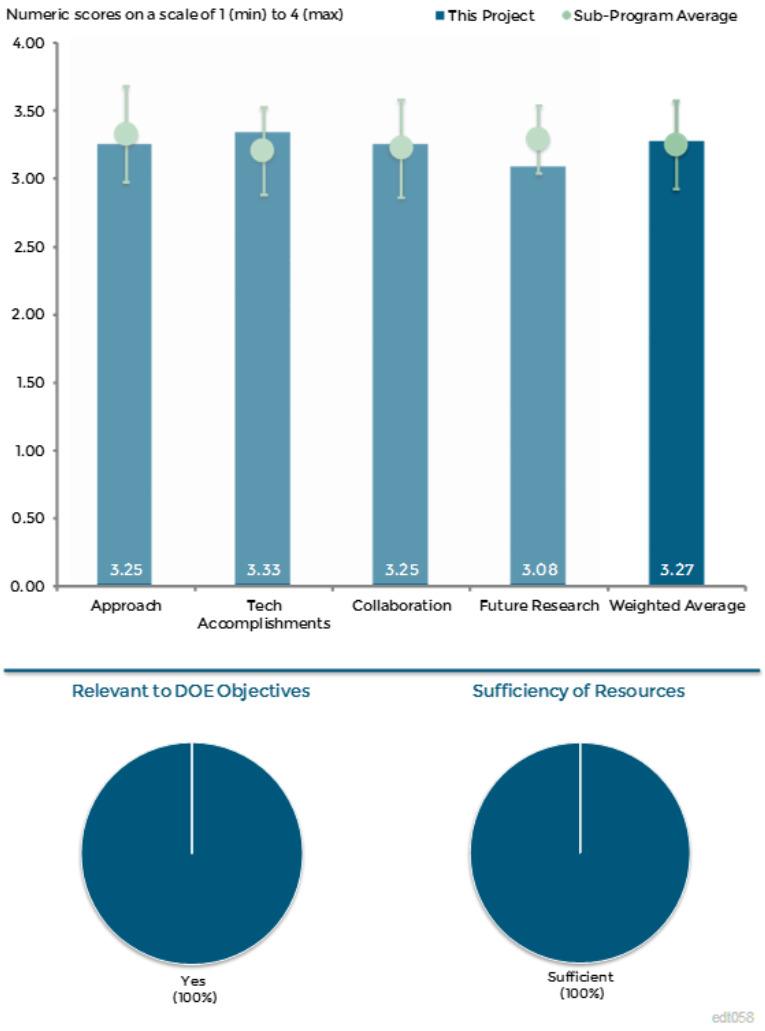

Figure 3-10 Advanced Low-Cost SiC and GaN Wide Bandgap Inverters for Under-the-Hood Electric Vehicle Traction Drives: Kraig Olejniczak (APEI, Inc.) - Electric Drive Technologies

Reviewer 3:

The reviewer suggested that the approach should state what those clever ways are to make apples to apples comparisons.

Reviewer 4:

The reviewer reported that this project advances know-how in the area of WBG power electronics by developing SiC and GaN traction inverters. GaN high-electron mobility transistor (HEMT) power device shall be advanced resulting in its probable application in a product that could be successfully commercialized. This project also aims to advance WBG inverter packaging and thermal management concepts including cost reductions by using in-house design of high temperature silicon on insulator (HTSOI) IC. Module package capable of the high temperature (250°C) applications shall be developed through this project. The reviewer concluded that this project does not address numerous issues related to the production intent design, what would be kW/liter, kW/kg and $/kW SiC and GaN inverters address commonly known production issues, such as EMI/EMC, dv/dt, and di/di problems.

Reviewer 5:
The reviewer relayed that the project is developing advanced EV power electronics using WBG switches.

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

Reviewer 1:
The reviewer declared that the progress, given the funding level and size of organization, has been excellent.

Reviewer 2:
The reviewer pronounced that this project had made reasonable progress.

Reviewer 3:
This reviewer said that progress on the inverters is progressing, but wondered what the comparison points are.

Reviewer 4:
The reviewer decided that the few technical accomplishments that were noted were good, and was impressed by the module inductance. This reviewer pointed out that no mention of the estimated production cost of such an inverter or switch was made, just several references back to GM estimated costs, which were not provided either. No doubt one can make a WBG inverter, and make it smaller, and make it lighter, and make it more efficient, but this reviewer wondered if it could be commercially viable in the DOE stated planning horizon for this project.

Reviewer 5:
The reviewer reported that the prototype SiC inverter is tested up to 30kW and efficiency of the inverter is determined. Power module is characterized over 25°C to 125°C for key parameters, such as, Rds on and Vds versus Ids data including clamped inductive load testing. Thermal analysis of the inverter assembly is carried out. Accelerated thermal testing of interface material is carried out to evaluate reliability of module.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer thought that having an OEM collaborate on designs is excellent, and that having the OEM use the design is outstanding.

Reviewer 2:
The reviewer concluded that APEI has good collaboration with NREL on modeling and GaN systems.

Reviewer 3:
The reviewer reported that Toyota, GaN Systems, NREL and University of Arkansas are collaborators in this project.

Reviewer 4:
This reviewer relayed that the project team was engaging OEM, suppliers, and national laboratories.

Reviewer 5:
The reviewer deduced the project team was ultimately designing, building, and testing an inverter in this project. This reviewer would have liked to seen a Tier 1 inverter partner or been advised on how Toyota was representing this competency and/or point of view.

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 team may work with Toyota to test their system in a vehicle, and that more cost analysis should be provided.

Reviewer 2:
The reviewer believed that there was lots of work left to do on this project and very little time

Reviewer 3:
The reviewer was not clear how other areas, like changes in control strategies to improve efficiency are impacted by this comparison, because the approach seemed to be focused on SiC versus GaN.

Reviewer 4:
It is not clear to this reviewer if this prototype includes the EMI filter, and asked that if it does, to please show the EMI test result next time.

Reviewer 5:
This reviewer said that given time and resources, future research looks impractical.

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

Reviewer 1:
The reviewer found that this project addresses DOE's quest for WBG power electronics, and speculated that it could be possible DOE-APEEM target could be met and/or exceeded.

Reviewer 2:
This reviewer decided that was one approach to meet DOE cost and performance targets is using the WBG switches. The team may provide a roadmap on potential cost reduction of WBG switches and their power inverters.

Reviewer 3:
This reviewer agreed that evaluating different approaches to reduce power electronics costs helps to lower the cost of EDV's and reduce our dependence on foreign oil.

Reviewer 4:
The reviewer supposed that if successful and commercially viable, the project would support the DOE goal, but questioned where the production costs will land, and therefore the viability.

Reviewer 5:
The reviewer relayed that the project looks at the application of WBG and how to gain the most out of these types of devices.

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

Reviewer 1:
The reviewer said they seemed adequate.

Reviewer 2:
This reviewer agreed that the team and its partners have all the resources to achieve the stated milestones.

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

Presenter

Angelo Yializis, Sigma Technologies International.

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 saw that the project appeared to be organized and coordinated with capabilities of project partners. The project incorporates an automotive supplier with experience in requirements and challenges associated with the use of capacitors in automotive electric drive applications. The project also appeared to the reviewer to be actively involved in efforts to commercialize the technology.

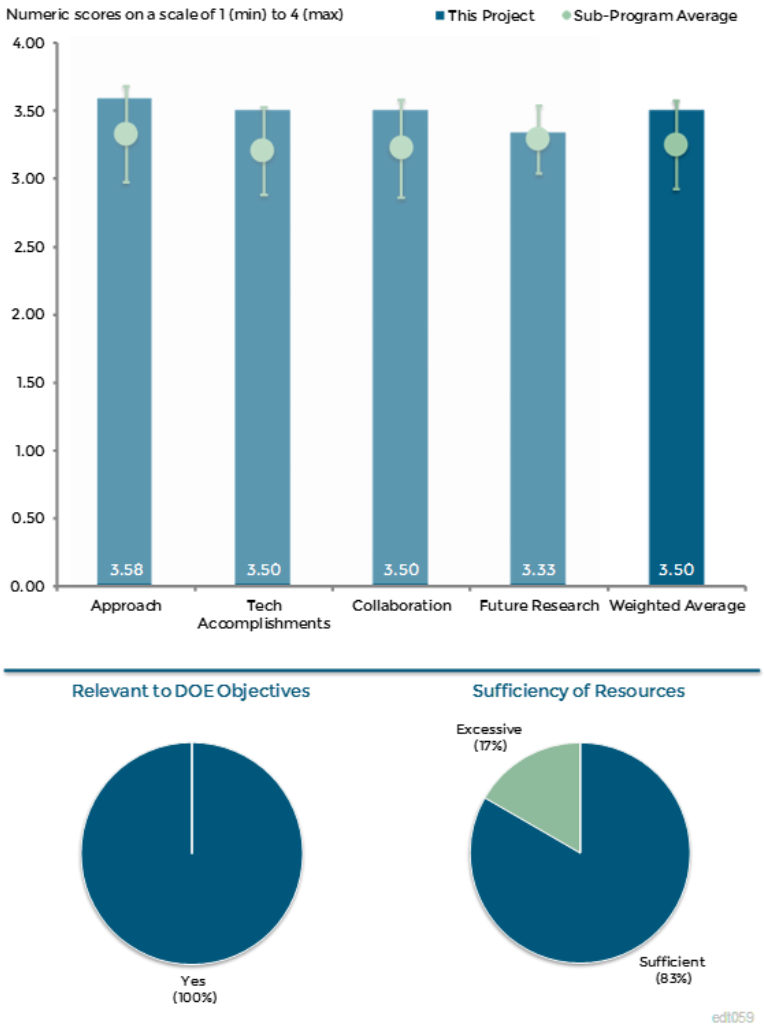

Figure 3-11 High-Temperature DC Bus Capacitors Cost Reduction and Performance Improvements: Angelo Yializis (Sigma Technologies International) - Electric Drive Technologies

Reviewer 2:

This reviewer thought that the approach being implemented on this project has potential to transform the capacitor industry, while addressing the goals set forth for this project. The presenter displayed a high level of competency in conventional capacitor technologies and their limitations, and clearly presented the advantages that distinguish this approach from conventional methods. This reviewer was concerned that this is a relatively new processing technique for capacitors, and quality control for mass production may require additional research beyond the demonstration scale and low volume production.

Reviewer 3:

The reviewer declared that the process of build, test, and improve the design has been proven to work on numerous programs and should work here. Also the approach is addressing the basic issue with bulk caps of today: larger, heavy capacitors with limited temperature range and lower ripple capacity as a function of increasing temperature. This project is developing a new capacitor based on new, ultrathin high strength dielectrics that promise to create high energy density capacitors capable of high temperature operation. The approach includes developing a package optimized for this construction technique that is appropriate for the automotive environment. The team is also building a model of the capacitor capable of supporting thermal

modeling of capacitor temperatures over various drive cycles, which aid in inverter design. The reviewer concluded that the sample package shown during the meeting will be impressive if it works.

Reviewer 4:

The reviewer stated that Sigma has a novel technology for fabricating multilayer polymer capacitors through sequential monomer and electrode deposition in a large-scale vacuum system. The capacitors have a high volume efficiency and low equivalent series inductance and the polymers have been specifically formulated for high temperature operation.

The reviewer further relayed that the goal is to replace large and heavy DC link capacitors that are fabricated by co-winding metallized polymer films. In addition, current polypropylene capacitors will not operate above 105°C under high ripple currents. Sigma's acrylate-base polymers will be able to operate above 140°C.

Reviewer 5:

The reviewer reported that the approach was to integrate the entire capacitor manufacturing chain in one step.

Reviewer 6:

The reviewer indicated that the approach of this effort is to develop a solid state polymer-multi-layer (PML) with prismatic shape to overcome limitations of polypropylene DC-link capacitors in transportation electrification applications. It has lower equivalent series inductance (ESL) and equivalent series resistance (ESR) in comparison to the state of the art. Its operating temperature is in the range of -40°C and 140°C

The reviewer believed it would be useful to include more information on what is expected regarding operation life cycle/time of the proposed technology and also some information on the method of determining such information.

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

Reviewer 1:

The reviewer said that the presenter provided detailed information that confirms this project addresses DOE goals, particularly the volume and cost of the capacitor. This person saw that progress had clearly been made in several areas including critical successes with the process development/setup.

Reviewer 2:

The project appeared to the reviewer to have made significant progress in demonstrating the ability to produce capacitors with performance at high temperatures. This person suggested that it would be helpful to compare the expected performance in terms of cost and volume to the DOE targets.

Reviewer 3:

The reviewer believed that the team is making very good progress toward delivering a production capacitor, and summarized their results: The team has developed a set of capacitor values based on past inverter project bulk capacitor requirements. This has been used to develop a baseline area for the generic capacitor building block which supports a cost effective method of supporting multiple capacitor values in production. Process development has continued with upgrades to the pilot line and an improved passivation process. The reviewer further commented that initial tests indicate that this process has the potential to develop excellent capacitors for use in an inverter. Additional progress has been made in the thermal model which will allow Delphi to characterize the thermal flux performance of the capacitors.

Reviewer 4:

The reviewer detailed that a majority of the reported effort was for optimizing the end terminations. After fabrication of the multilayer polymer monoliths, the ends are subjected to plasma to expose the electrodes. The resistance of the end terminations must be reduced for low ESR and high ripple current. The surface resistance

was as low at 10 milliohms/meter; however, the targeted surface resistance was not defined. Life tests were performed at temperatures between 125°C and 160°C. The reviewer thought it would be useful demonstrate capacitor reliability as a function voltage and temperature in the future.

The reviewer conveyed that excellent energy densities were reported at room temperature and high electrical field.

Reviewer 5:
The reviewer affirmed that the technical accomplishments and goals include reducing the cost, size and weight of the DC-link capacitors by at 50%, while increasing the durability of the capacitor operation in high temperature environment.

Reviewer 6:
The reviewer reported that prototype capacitors with large capacitance have been produced.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer saw that the collaboration with the automotive supplier appeared to be very strong in the project to help understand the performance requirements of the capacitors for automotive applications. The presentation also mentioned that there are plans to include a capacitor OEM in the future.

Reviewer 2:
This reviewer declared the collaboration with Delphi and the DOE laboratory was excellent.

Reviewer 3:
The reviewer determined that the project involved a good combination of expertise including an application-oriented partner and other experts in processing and materials science.

Reviewer 4:
The reviewer confirmed that the team has the appropriate skills to complete the task and seem to be working well together based on the results to date. This person asked when the capacitor manufacturer will be added to the team.

Reviewer 5:
The reviewer reported that there is a collaboration between Sigma Technologies, Delphi and ORNL.

Reviewer 6:
The reviewer relayed that the program team members involve an inverter manufacturer (Delphi) and a national laboratory (ORNL). Delphi provides testing and guidance for capacitor banks that will comprise the DC bus capacitor. ORNL will develop thermal models for difference capacitor configurations.

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 believed that future efforts for this project are well planned, including next generation capacitors, more detailed cost analysis, and development of a business plan.

Reviewer 2:
The reviewer declared that the future work related to cost analysis seemed to be a critical element of the project to determine if the developed capacitors can support the push to reduce costs of the electric drive system.

Reviewer 3:
The reviewer reported that the proposed work continues the build, test, fix process along the path to the final product. The tasks identified are appropriate for this project. The only item that this reviewer had any concern with was the voltage rating of the part – if 600 Volt would be high enough for potential boosted systems of the future, which will be using 750 to 900 Volt devices and may see a boosted high-voltage bus of 600 to 650 Volt.

Reviewer 4:
The reviewer commented that future work may invest more time to test the capacitors under the EV condition, such as applying large ripple current at elevated temperatures. The reviewer thought it would not be very useful to test the capacitor under DC without ripple, and that it was still not very clear whether the plasma etching can help the electrical connections and carry high ripple current.

Reviewer 5:
The reviewer described how the project team will complete the additional pilot line improvements. The complete package design and the evaluation of first and second generation of capacitors will be done during 2015. During 2016, testing of the packaged PML DC-link capacitors will be conducted. In addition, it will be implemented and tested on a Delphi inverter. Furthermore, the business plan transition into production will be conducted in 2016.

Reviewer 6:
The reviewer relayed that the scale up plans have been implemented to produce 800 microfarad DC-link capacitors operating at 400 V. The targeted temperature range and volume requirements have been specified. The reviewer asked if ripple current will also be measured for the capacitor banks.

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

Reviewer 1:
The reviewer explained that this project supports the DOE objectives to reduce petroleum because smaller, cost effective, and more robust capacitors would enable reducing the size of existing inverter systems for electric drive technologies. The reduced size could make electric drive technologies cost less and make them easier to package within the vehicle to support a wider range of uses.

Reviewer 2:
The reviewer declared that the summary chart, Slide 31, indicates that this project will meet or exceed the DOE goals for capacitors, which are one of the largest components in today's inverters.

Reviewer 3:
The reviewer reasoned that smaller, lower cost capacitors will facilitate the electrification of powertrain, thereby yielding higher fleet fuel economies.

Reviewer 4:
The reviewer stated that DC link capacitors are a critical component in power inverters for electric vehicles.

Reviewer 5:
The reviewer reported high temperature and cost reduction.

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

Reviewer 1:
The reviewer said that the resources appear to be sufficient and the project appears to be making good progress.

Reviewer 2:
This reviewer shared that opinion that the project is on schedule and resources are sufficient.

Reviewer 3:
The reviewer said the project has unique capabilities and close collaborations with critical partners.

Reviewer 4:
This reviewer indicated that there are enough resources among the three partner institutions to successfully carry out the proposed work.

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

Presenter

Dan Tan, General Electric.

Reviewer Sample Size

A total of six reviewers evaluated this project.

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

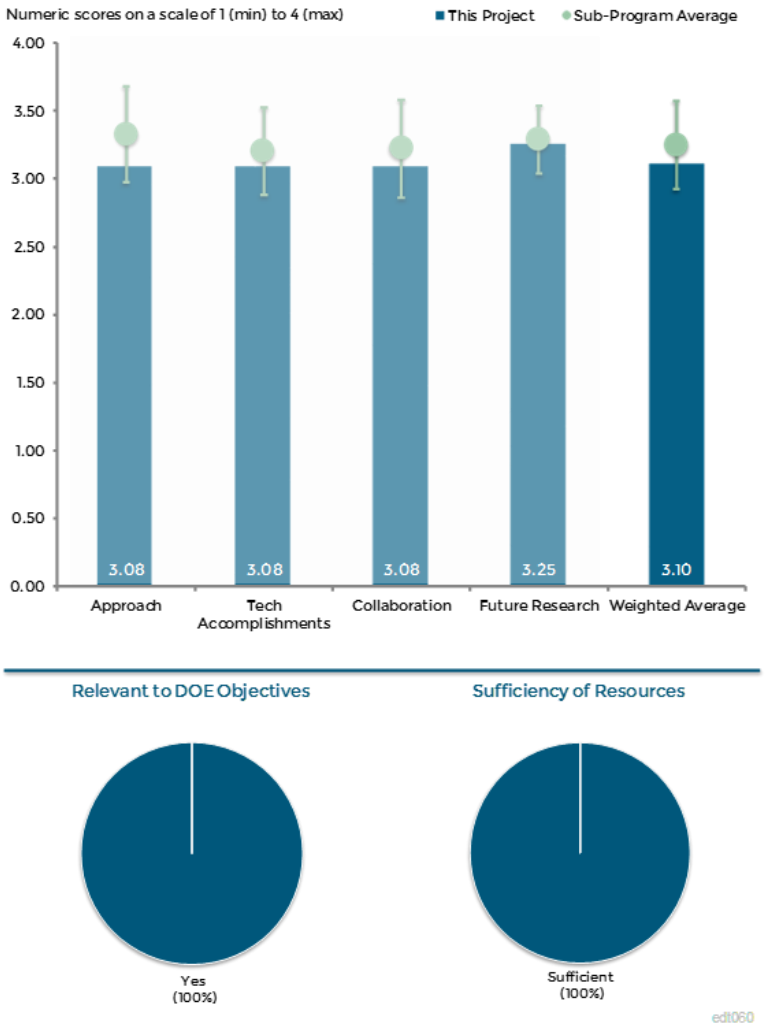

Figure 3-12 High-Performance DC Bus Film Capacitor: Dan Tan (General Electric) - Electric Drive Technologies

Reviewer 1:

The reviewer found the approach implemented on this project to be generally well-planned, as it utilizes existing processing techniques, but predicted that it will require some challenging process variations/improvements as thinner films are targeted.

Reviewer 2:

The reviewer reported that the development effort focuses on thinning polyetherimide (PEI) film, which is a commercially available material. This dielectric has sufficient properties to meet the DOE specifications for DC link capacitors including high temperature performance and low dielectric loss. This reviewer anticipated that this material will enable capacitors to operate at high ripple capability at high temperature. Thickness reduction is the main goal with dielectric layer thicknesses in the three to five microns. Thinner layers will increase the volumetric efficiency and lower the overall capacitor cost.

Reviewer 3:

The reviewer judged that the project covered an important technological topic, but noted that some of the system level parameters are not clearly outlined and correlated to the materials. This person asked the project team to please provide more information, such as mathematical modeling, to prove how the project team will achieve the 200,000 hour claimed operating life.

Reviewer 4:

The reviewer said that the project appeared to be focused on improving the dielectric constant and being able to produce a thinner film to reduce volume and cost. This person asked if there were other significant barriers that are expected when the project transitions into building capacitors, and what test criteria would be applied to the fabricated capacitors.

Reviewer 5:
The reviewer thought that the approach is typical for a new film capacitor, but was concerned about the upper temperature limit of 180°C, which appears to be related to aerospace more than automotive. This person wondered if it was driving the cost of the capacitor. The team is using multiple film suppliers and is optimizing the correct parameters in terms of film capacitors. The reviewer liked the early involvement of mainline capacitor suppliers as it enables production parts sooner.

Reviewer 6:
The reviewer suggested that the project may invest more on film processing and cost analysis.

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

Reviewer 1:
The reviewer saw a wide range of technical accomplishments on this project, which indicates that there is a great likelihood of incremental success through well-formulated process development and experimentation.

Reviewer 2:
The reviewer agreed that there was significant progress on producing 3um thick PEI film.

Reviewer 3:
The reviewer said the project had evidently worked with production extruders to scale up the process. The material appears to be capable of operating at high temperatures. It appeared to the reviewer from the presentation that work is continuing to overcome defects within the extruded film. The work to reduce defects within the film appears to be the current challenge. Despite the challenges the project says it is on track to produce a capacitor. The reviewer suggested that it might be useful to compare the state of the current material and the project goals to the DOE targets. Most of the slides appeared to focus on the extruded films. This reviewer concluded that some information on the progress associated with the nano-coating of the films to enhance dielectric strength would be of interest.

Reviewer 4:
The reviewer believed that progress is reasonable but was concerned that the aerospace performance goal is impacting the overall progress. The reviewer understands the need to support both. Film processes are improving from multiple suppliers using different processes. The reviewer revealed that the go/no go decision point is coming up and will require six capacitors of specified requirements, but those requirements were not specified. This person concluded that there has been good progress made, but there are still lots to be done and was unsure if the schedule will be met.

Reviewer 5:
The reviewer requested the project team to please provide additional information on what are the typical values of capacitances (in terms of farad) that this project has so far developed and what will be the target values at the end of project. This person asked what the volume is currently, and what the lifetime and reliability are currently like.

The reviewer also requested a graph or some numerical examples representing size of the capacitor for various power levels for car inverters, information on mechanical properties/thermal properties, and ESR/ESL parameters by the capacitor size.

Reviewer 6:
The reviewer reported that PEI films have been fabricated in the 3-5 micron range, with the dielectric permittivity, loss and breakdown of the films as a function of temperature fully characterized.

The reviewer was of the opinion that films in the three-micron thickness range will remain a challenge. Nanolayered silica coatings on the PEI films have shown improvement in the room temperature dielectric breakdown. The reviewer thought it would be interesting to also characterize the dielectric breakdown of silica coated PEI at 150° C.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer remarked great collaboration with film manufacturers and Delphi.

Reviewer 2:
The reviewer remarked that the project includes collaboration and coordination with key members of the capacitor industry and suppliers, as well as an application specific collaborator.

Reviewer 3:
The reviewer summarized that GE's team is made up of an inverter supplier for requirements, extruded film suppliers, and appropriate suppliers of the required expertise, which seem to be working well together or at least on their tasks. The reviewer believed that the expertise is available to complete the project.

Reviewer 4:
The reviewer said that the collaboration with partners appears to be strong. The collaboration with an automotive supplier appears to be beneficial, but it seems their involvement will become more critical once a capacitor is produced that can be tested. The project appears to have established strong partnerships with various suppliers along the supply chain.

Reviewer 5:
The reviewer observed that GE is collaborating with two independent film manufacturers to scale the PEI materials into mass produced film. There are also plans to team with companies along the entire capacitor manufacturing supply chain. The reviewer detailed that in addition to the film manufacturers, GE will engage with companies specializing in metallization and capacitor fabrication.

Reviewer 6:
The reviewer acknowledged that there is a collaboration between GE and Delphi to develop new material to develop high temperature capacitors. The reviewer believed there should be collaboration between these DOE funded companies and at least a university partner.

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 believed that the future plans, which target the primary barriers associated with the transition to thinner film capacitors and fabrication of prototype thin film capacitors, are crucial.

Reviewer 2:
The reviewer stated that it is critical to invest more on film processing and the valuation of the capacitors under HEV power inverter conditions.

Reviewer 3:
The reviewer judged the proposed future work to be appropriate for the current state of the project. The tasks continue the existing development path relative to films and processing.

Reviewer 4:
The reviewer revealed that GE will continue to optimize the PEI film quality for thicknesses less than 5 microns. Specific milestones include the fabrication and testing of prototype capacitors.

Reviewer 5:
The reviewer indicated that the future work appeared to focus on developing the film material and nano-coating. The future work related to cost analysis is important to determine if the new materials and processes are compatible with the need to reduce cost. The future work lists building and testing capacitors, but this person thought that more information would be beneficial because this appears to be a critical step in the project to demonstrate success.

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

Reviewer 1:
The reviewer declared that this project supports the DOE objectives to reduce petroleum because smaller, cost effective, and more robust capacitors would enable reducing the size of existing inverter systems for electric drive technologies. The reduced size could make electric drive technologies cost less and make them easier to package within the vehicle to support a wider range of uses.

Reviewer 2:
The reviewer affirmed that high temperature capacitors are critical to the DOE program target.

Reviewer 3:
The reviewer detailed that this project supports the DOE objectives through introducing novel capacitors with potentially lower size and hopefully longer lifespan or reliability. This would be very useful in advancing the field of power electronics, as DC-link electrolyte capacitors are one of the points of failure for power electronics interfaces.

Reviewer 4:
The reviewer believed that the results were promising in that incremental improvements are likely, which address DOE objectives. Quality control on films that are 4µm and thinner may be a major limiting factor in fully reaching DOE goals.

Reviewer 5:
The reviewer considered DC bus capacitors to be a critical electronic component on power converters for electric vehicles, and speculated that high temperature capacitors may eliminate costly cooling loops and reduce overall system cost.

Reviewer 6:
The reviewer pointed out that this is one of three capacitor programs aimed at reducing the size and cost of the bulk capacitor, which is one of the largest components in the inverter.

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

Reviewer 1:
The reviewer saw that resources appeared to be sufficient.

Reviewer 2:
The reviewer judged that the team has good resources to carry out the project.

Reviewer 3:
The reviewer decided that resources were sufficient for this project based on progress to date.

Reviewer 4:
The reviewer thought that it will be great if the project has had more internal resources rather than relying on external resources.

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

Presenter

Balu Balachandran, Argonne National Laboratory.

Reviewer Sample Size

A total of five reviewers evaluated this project.

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

Reviewer 1:

The reviewer considered the approach to be interesting and well executed. The concept for applying the lead lanthanum zirconate titanate (PLZT) film in a reel-to-reel process seems feasible.

Reviewer 2:

The reviewer saw a clear, sound approach that addresses the fundamental challenges that needed early resolution for this technology. This person liked the adoption of 3D printing the nozzles to quickly test nozzle designs.

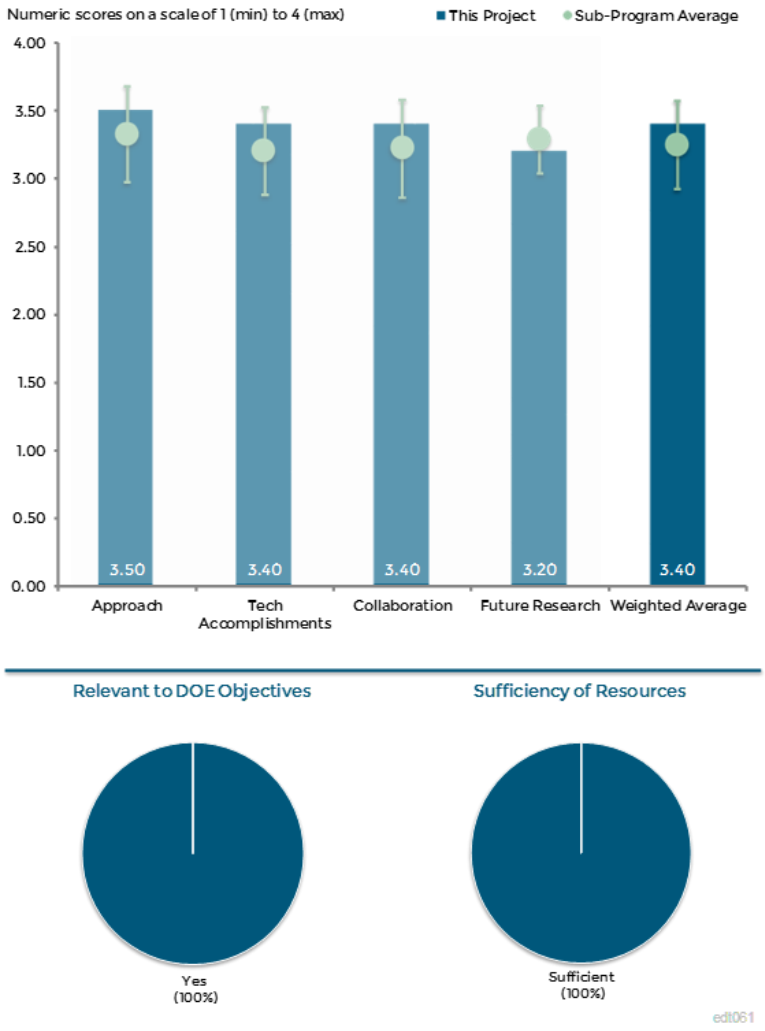

Figure 3-13 Cost-Effective Fabrication of High-Temperature Ceramic Capacitors for Power Inverters: Balu Balachandran (Argonne National Laboratory) - Electric Drive Technologies

Reviewer 3:

The reviewer summarized that this project addresses the need of a low-cost, high temperature, and smaller footprint capacitor for DC bus filtering applications in power converters and a team consisting of a Tier 1 inverter manufacturer (e.g. Delphi), leading capacitor designer (e.g., Sigma Tech), and university partner, makes it a winning team with a great potential for successful completion of the project.

This reviewer commended the PI and co-PIs for project work carried out so far, and encouraged the project team to look into peripheral applications of the developed technology, such as using developed material and technology for safety rated capacitor required for high temperature applications.

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

Reviewer 1:
The reviewer thought the accomplishments thus far were impressive and were foundational for the successful continuation of the project, and thought the validated results from a potential Tier 1 user of the developed capacitors was good.

Reviewer 2:
The reviewer stated that the PLZT material is characterized over temperature, over frequency, over a voltage range including data for energy density and voltage withstand capability of PLZT material at room temperature and elevated temperatures. Manufacturing processes of PLZT base material is developed and could be scaled for mass manufacturing.

Reviewer 3:
The project appeared to the reviewer to be on track in terms of technical accomplishments. The capacitor technology appears to meet both temperature and dielectric constant targets. The reviewer recommended that the cost metric should be better defined and the cost performance of the technology should be more fully quantified as it matures.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
It reviewer observed that Argonne National Laboratory (ANL) has worked closely with Delphi in the validation of the material performance, and that ANL also appears to be working closely with possible manufacturers of the material.

Reviewer 2:
The reviewer determined that this project has a very good, complimentary team; the basic science and research from ANL; materials test, characterization, and science of processing from Penn State University; an experienced processor with knowledge to scale from Sigma Technologies; and a Tier 1 user of the product from Delphi. The reviewer would like have seen a real, traditional, high-volume film capacitor manufacturer on this team too just to keep it commercial

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

Reviewer 1:
The reviewer thought the next steps are logical, systematic steps and the plan for these steps seems considerate. Ultimately installing and testing as DC-link capacitors in a traction-sized inverter will be telling.

Reviewer 2:
The reviewer said the project team had thought out the next steps.

Reviewer 3:
The reviewer suggested that the investigators more seriously study the reliability of the thin film in relation to thermal cycling to verify that cracking does not occur over time.

Reviewer 4:
The reviewer reported that future research tasks are targeted prototyping, production, and commercialization of the high temperature, low cost, and high packaging density PLZT capacitor technology.

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

Reviewer 1:
The reviewer said that high temperature, low cost capacitor technology is a critical element for future vehicle electronics (especially WBG devices).

Reviewer 2:
This reviewer agreed this project absolutely addresses the DOE objectives. Size, weight, and cost of power electronics are contributing to the slow up-take. Advanced DC link capacitors in traction inverters addresses all three of these items simultaneously.

Reviewer 3:
The reviewer maintained that the availability of high temperature, low cost, and high packaging density capacitor is a must for successful adoption of WBG power electronics, which aligns with the DOE EV Everywhere objectives.

Reviewer 4:
The reviewer reported that this project works on density, temperature rating, and cost.

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

Reviewer 1:
The reviewer said the project was well resourced in terms of labor, expertise, and funding.

Non-Rare Earth Motor Development: Tim Burress (Oak Ridge National Laboratory) - edt062

Presenter

Tim Burress, Oak Ridge National Laboratory.

Reviewer Sample Size

A total of five reviewers evaluated this project.

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

Reviewer 1:

The reviewer thought the technical barriers were quite well defined and theoretical foundations are sound. This person said there seems to be some lack of integration with other efforts, in terms of coordinating with absolute end users, e.g. automotive and aerospace industry who could potentially benefit from the technology.

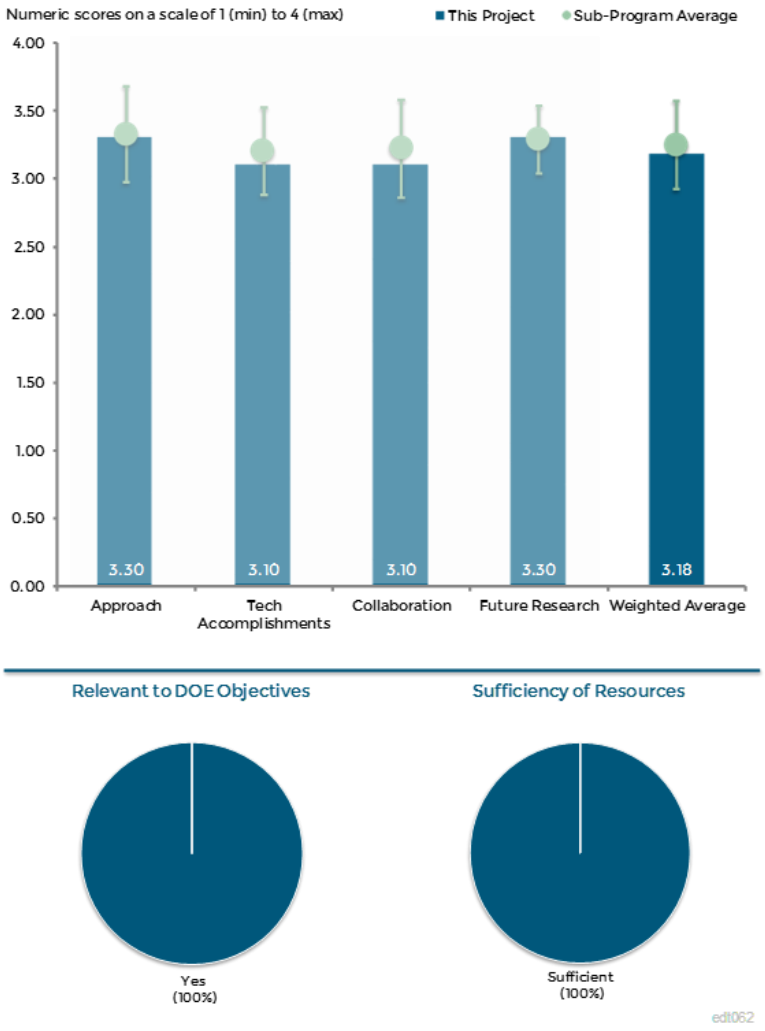

Figure 3-14 Non-Rare Earth Motor Development: Tim Burress (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 2:

This reviewer was of the opinion that the scope of the work is very broad but it is not clear how the various technology pieces complement each other, and also the improvement in performance is not very clear.

Reviewer 3:

The reviewer suggested the team try to tie together the disparate efforts being made in multiple directions within the program, and maybe pick the one or two most exciting/most promising technologies to work on.

The reviewer indicated that on the motor design effort, the team has a good approach of first trying to find by simulation motor designs that could meet DOE Electric Drive Technologies 2020 targets, then proceeding to fabricate motor. This could be made a standard requirement of all similar projects.

In general, though, this person thought that the machines being studied are extensions of well-known topologies, limited by the same design limits related to electrical and magnetic loading, and thermal and mechanical constraints. It appeared to this reviewer that the advances being made on the lamination steel and the modeling capability can help make fundamental improvements to machine technology. This person would recommend demonstrating this technology on an existing baseline design where apples-to-apples comparisons can be made, rather than confounding it with changes to machine topology. Future extensions of the program can then consider selecting an optimal machine topology for the new technology.

Reviewer 4:
The reviewer agreed that even without using RE materials, 2020 cost targets are challenging.

The reviewer advised more decision points to better focus the target area for study for maximum gains: materials, motor modeling accuracy, design process and optimization, high efficiency steel, impacts of residual stress in electric steels, down-select motor designs.

The reviewer thought the process of down-selection of a final motor configuration/design was a little unclear, but understands there will be optimization using the super computer and selection based heavily on cost and manufacturability. The approach was to develop alternative motors that do not use RE magnets. Modeling of soft magnetic materials and residual stress effects. Synchronous reluctance, NRE permanent magnet, brushless field excitation, or a combination of two or more of the above.

The reviewer believed that chemical vapor deposition to increase Si content in steels was innovative, new and highly beneficial if it turns out to be a cost effective process.

The reviewer identified using micro-magnetics modeling to simulate magnetic properties in regards to steel with residual stresses as a high value proposition, as there is currently no good method of modeling losses in magnetic steels, especially with residual stresses and anomalous loss.

The reviewer thought the project was broadly scoped, looking at modeling techniques, new materials, and new motor designs, and would be interested to see how it all comes together.

The reviewer said that the integration with other efforts showed good usage of industry and other laboratories, and that the plan for collaboration is very good.

Reviewer 5:
The reviewer pointed out that this project has very similar approach to the long running GE project, consisting of identification of more than 10 new motor concepts, and down-selection of promising candidates with more detailed design and prototypes. The reviewer declared that the most promising candidates in this project are brushless field excitation motors and the new type of synchronous reluctance motor. For GE the best candidates are flux switching dysprosium (Dy) free PM motor, spoke ferrite motor, and DC biased SRM. This person wondered how well these two projects are coordinated by DOE to ensure overall projects goals.

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

Reviewer 1:
The reviewer indicated that work was about 38% complete, which is compatible (or better) with the total time span of the project, and that the desired focus at each year end has been clearly indicated with bar graph, and table showing various milestones.

Reviewer 2:
The reviewer reported that the ORNL synchronous reluctance motor has been completed and is on their dyno. Efforts to model magnetic effects from residual stresses have begun and appear promising. The reviewer thought this capability would be quite useful for better efficiency/loss prediction. It seemed to this person that although there is much to do in terms of modeling and assessing the other motor topologies, the team is on course with respect to the project plan.

Reviewer 3:
The reviewer saw that good progress had been made on the core loss mitigation, magnet modeling, and thermal management. The latter topics may have some overlap with other programs within the same office. The reviewer believed that there may be an opportunity to streamline research on these topics.

The reviewer also stated that advances made in the machine topology were not obvious, and it was not clear what the true innovations in the machine design are. Synchronous reluctance and brushless field excited motors have been studied extensively by others, but perhaps this team has come up something interesting that it is yet to share in public.

Reviewer 4:
The reviewer said that it was not clear whether the accomplishments are focused on new materials or new ways of processing/modeling materials or motor topologies. This has to be clarified and better well-defined.

Reviewer 5:
The reviewer pointed out that ORNL claims that the new motor concepts have similar performance compared to baseline 2010 Prius motor, but that the power and Torque curves on Slide 18 do not really confirm that claim. Also, the reviewer wondered if comparing the new concepts against 2010 Prius motor, which is now two generations old, was a good idea to design the future motor.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said there is good collaboration between different institutions as well as various technology areas.

Reviewer 2:
The reviewer considered collaboration and coordination with various institutions, i.e., academia and industry, to be excellent. This reviewer believed that it would add more benefit if some coordination was also done with end users of the final product, e.g., automotive, aerospace, and other industries who use electric motors in a complete system.

Reviewer 3:
The reviewer saw that there was opportunity to collaborate with the other teams and maybe even broader collaborations with motor development teams to study the impact of the improved materials and thermal management techniques on a broad variety of motor types, and to compare their performance. Perhaps starting with the other teams developing motors with funding from the same program office.

Reviewer 4:
The reviewer reported that collaboration is to occur with other laboratories and industry, but that it was unclear how close or coordinated the effort is.

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

Reviewer 1:
The reviewer expressed that localized characterization of laminations with regard to losses and stress would be the most interesting and useful outcome of this project.

Reviewer 2:
The reviewer thought the proposed future work seemed reasonable but it would be helpful to bring more clarity about the motor topologies evaluated and how the sown-selection will be performed.

Reviewer 3:
The reviewer concluded that the project is well planned, but listed a few additional issues that will add benefit: First, it may be important also to think ahead about how to recycle the materials at the end of the lifetime of the motors. Second, it would be beneficial if a comparison of the material properties of the proposed NRE versus the existing RE materials was provided. This comparison will help better understand the complete picture.

Third, manufacturing process for high volume production should also be thought ahead, because eventually that will be necessary. Fourth, more detailed references, in the form of patents, papers, etc., on existing work or SOA will be helpful.

Reviewer 4:

The reviewer said that while it may be too early to do for some of the technologies being pursued, the team should really try to quantify potential benefits of the different approaches being pursued, e.g., if iron losses were halved, what the impact on efficiency, thermal management, and rating are. The reviewer thought that it will be good to see how the advances in material technology would impact a more traditional induction motor design.

Reviewer 5:

The reviewer determined that the project has a broad scope and many potential paths for research and combining architectures, materials and modeling techniques. It was a little unclear to this reviewer what the decision points would be and what direction they would go at certain milestones, based on different scenarios of possible findings. The reviewer concluded that this may too be open-ended as well.

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

Reviewer 1:

The reviewer stated that the project is relevant because it explores technologies that can reduce dependence on RE materials as well as better modeling and hence prediction of machine performance

Reviewer 2:

The reviewer determined that the project focuses on low cost manufacturable motors, materials and design techniques, and that ultimately cost is the largest barrier to adoption of electrification, so the project definitely addresses this goal.

Reviewer 3:

The reviewer reported that the team has clearly focused on developing technology that will make electric/hybrid electric drivetrains more cost effective, which in turn should help with DOE's objective of petroleum displacement.

Reviewer 4:

The reviewer detailed that the project may not directly influence the petroleum displacement, because it is about replacement of the existing motors which use RE materials. If petroleum displacement in terms of vehicular fuel economy is considered, then it will not displace petroleum consumption. However, if the cost of getting RE material and its manufacturing process involve more petroleum compared to NRE materials, then it may save fuel in an indirect manner.

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

Reviewer 1:

The reviewer thought that the resources would be sufficient for a program focused on the key innovations being made within the program, but that the team resources may be stretched if it proceeds full speed on all the fronts being currently explored.

Reviewer 2:

This reviewer decided that the resources seem sufficient based on the level of effort.

Reviewer 3:
The reviewer indicated that the resources at ORNL are vast, algorithm developers for new modeling techniques, super computers and testing capabilities all uniquely position them to do great things with this work.

Reviewer 4:
The reviewer determined that the resources indicated were reasonable.

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

Presenter

Doug DeVoto, National Renewable Energy Laboratory.

Reviewer Sample Size

A total of six reviewers evaluated this project.

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

Reviewer 1:

The reviewer considered this plan very clear and well-designed. Results from this project are helpful to all WBG projects expecting to take advantage of higher operating temperatures and will be operating at higher heat fluxes.

Reviewer 2:

The reviewer determined this was a well thought out and systematic approach.

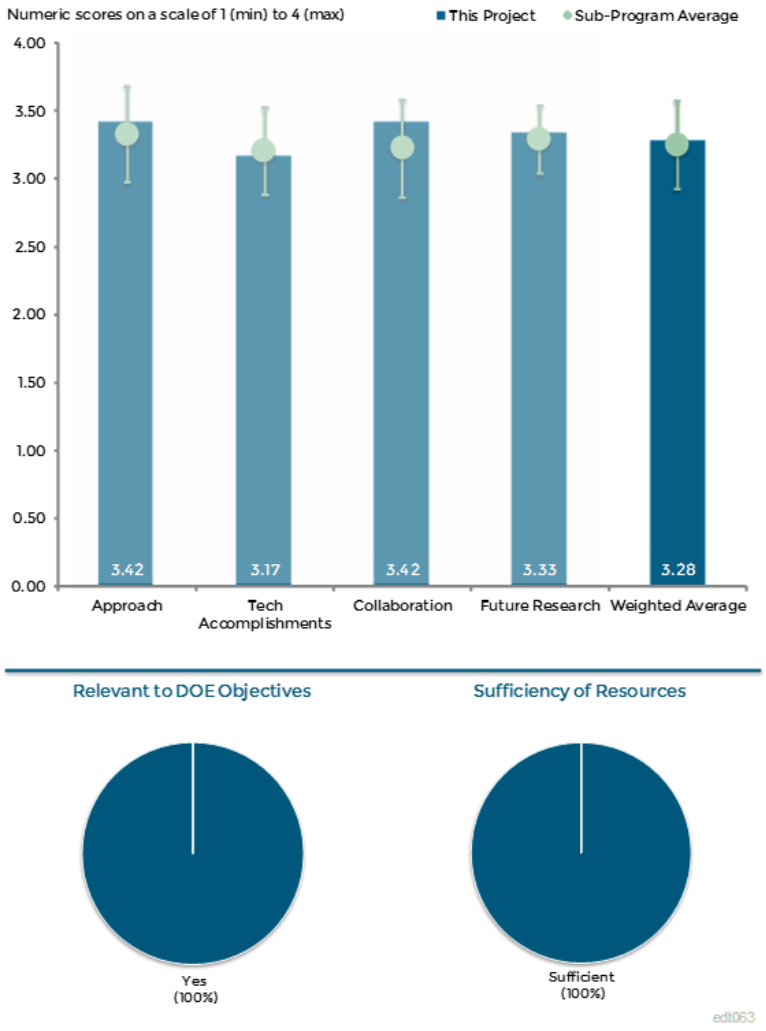

Figure 3-15 Performance and Reliability of Bonded Interfaces for High-Temperature Packaging: Doug DeVoto (National Renewable Energy Laboratory) - Electric Drive Technologies

Reviewer 3:

The reviewer reported that sintered-silver bonds are developed, thermal cycling is executed followed by inspection of sintered bonds, and data is collected data to develop failure models of sintered bond.

Reviewer 4:

The reviewer thought that using test coupons of different CTE's with thermal cycling to induce stress is a good idea, but pointed out that they had never seen an application where a square or rectangular device (die) is placed between round materials. The reviewer suggested perhaps a coupon with 90° corners would be more realistic to actual applications.

Reviewer 5:

The reviewer found a lack of systematic approach to address the performance optimization or reliability evaluation, and claimed that it was simply performance evaluation by testing, and therefore technical innovation was not significant.

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

Reviewer 1:
The reviewer observed that the project is proceeding to plan and yielding results needed for next steps.

Reviewer 2:
This reviewer relayed that modeling updates are progressing, but wondered if a biased humidity test could be included with the thermal cycle tests to determine if the silver material will survive in a typical automotive environment (e.g., no dendrite). The reviewer recommended looking at Automotive Electronics Council (AEC) Q101 to see how packaged parts are qualified, and possibly adding some of those tests to testing efforts.

Reviewer 3:
The reviewer reported that the PI has established a procedure for material characterization and sintered silver bond degradation model. The reviewer thought that it could have been a great idea to change bond interface area and determine how CTE mismatch affects bond interface life and reliability if bind surface area changes by a factor of +0.2 to -0.2 from area considered in this project.

Reviewer 4:
The reviewer said the achievement in FY 2014 was not clearly shown in the presentation.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer indicated that a good set of companies are mentioned as collaborators including ORNL.

Reviewer 2:
This reviewer agreed that there was a well-rounded and represented team.

Reviewer 3:
The reviewer noted that the collaborations have increased from last year.

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

Reviewer 1:
The reviewer considered the future work to well defined, but recommended that when looking at bond pad geometries to reduce stress, the project team should also add to the geometries how they may affect the thermal performance.

Reviewer 2:
The reviewer detailed that evaluation of low-pressure and no-pressure sintering is identified, which could be quite useful for industries, and that geometry area optimization is proposed.

Reviewer 3:
The reviewer's only feedback is for the project team to also consider crack formation and propagation when heating/cooling is from the inside-out as a powered semiconductor would do between two CTE mismatched materials.

Reviewer 4:
This reviewer does not see a relevant amount of reliability work conducted or planned for the future.

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

Reviewer 1:
The reviewer considered this as a companion project for all the WBG projects. The reviewer felt as though some of the WBG projects are focused on efficiency, size, weight, etc., but will not be able to take advantage of these items unless or until we all understand how to package semiconductors at these temperatures and heat fluxes. The reviewer concluded that this project helps us to understand those issues.

Reviewer 2:
The reviewer identified this as this project as providing the type of detailed understanding of materials in automotive application necessary to achieve cost reduction.

Reviewer 3:
The reviewer maintained that the proposed method could lower manufacturing costs of power converters and also it could raise reliability of electric drivetrain, which could lower cost of product and increase adoption of electric vehicles which could fulfill DOE objective of EV everywhere.

Reviewer 4:
The reviewer agreed that lowering the cost of power electronics and improving reliability helps to enable the market for power electronics.

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

Reviewer 1:
The reviewer stated that funding and people appear to be adequate to execute the project.

Electric Motor Thermal Management Research and Development: Kevin Bennion (National Renewable Energy Laboratory) - edt064

Presenter

Kevin Bennion, National Renewable Energy Laboratory.

Reviewer Sample Size

A total of seven reviewers evaluated this project.

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

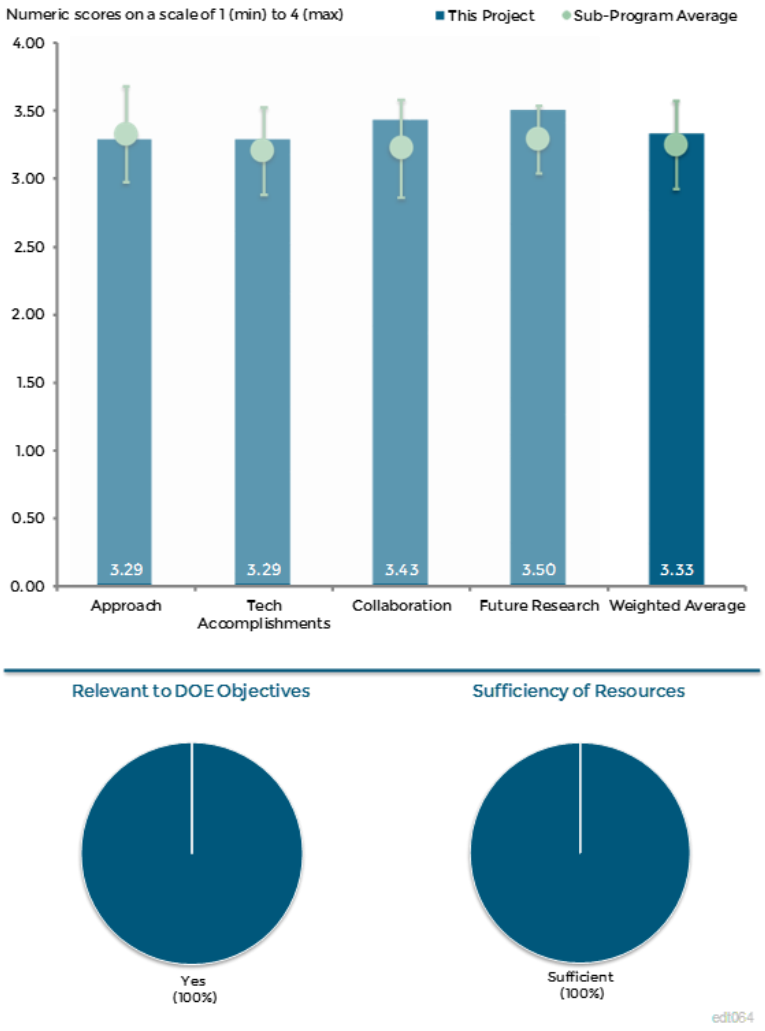

Figure 3-16 Electric Motor Thermal Management Research and Development: Kevin Bennion (National Renewable Energy Laboratory) - Electric Drive Technologies

Reviewer 1:

The reviewer indicated that the approach NREL is taking is very beneficial to industry, as data on the passive thermal circuit materials within motors is not widely known by manufacturers. The reviewer also thought that heat transfer coefficient is also very important to understand when making motor design tradeoffs and cooling method choices, and that the data NREL seeks in this set of experiments will be extremely valuable to the automotive motor community. The reviewer suggested that it would also be great to publish and present results along with data from other candidate cooling methods for motors.

Reviewer 2:

The reviewer declared it very systematic.

Reviewer 3:

The reviewer evaluated that the approach was good and was tackling several important areas, but recommended that more details that make the testing more realistic to what takes place in a real motor should be included.

Reviewer 4:

The reviewer believed that this is a very good general topic given the electromagnetic room available in some motors that can be taken advantage of with improved cooling. The team is taking a very reasonable approach to investigate this.

The reviewer thought that one interesting measure would be how much higher the peak load capability of the various electrical machine types is versus their steady state capability. Presumably the former is not thermally

limited but the latter is. That will help quantify the benefits, and potentially help down-select machines in which the improvements in thermal performance would make the most impact. More details would of course have to be considered later because several factors are at play. It may be worth exploring this with the motor development partners the team is collaborating with.

Reviewer 5:
Reviewer 6:
The reviewer acknowledged that understanding thermal characteristic of the motor is quite complicated as it depends on the construction/packaging of the motor and type of winding structure, and that NREL is making good efforts in this area.

Reviewer 7:
The reviewer judged technical barriers to be correct, but perspectives are not very clearly described. For example, life has been indicated as a barrier. It was not clear to this reviewer in what sense the term life is used. It was also perceived that thermal management involves size and weight constraints on the overall system, which can be barriers as well.

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

Reviewer 1:
The reviewer said that NREL has made significant progress in the areas of heat transfer coefficient measurement for jet impingement. Measurement of material properties for passive thermal circuit materials and thermal FEA modeling for motors. The reviewer expected the information sought will make that bank of data more accurate.

Reviewer 2:
The reviewer reported that work is about 38% complete, which is compatible with the total time span of the project. Although desired focus at each year end has been indicated, this reviewer thought a comparison chart or bar graph showing the desired milestone versus accomplishment would have been better to understand the status.

Reviewer 3:
The reviewer saw good progress but thought more quantitative results should be shared.

Reviewer 4:
The reviewer asked what the impact of end winding impingement cooling on coil hotspot temperature was, and speculated that this may be most beneficial to machines with temperature capability substantially more than automatic transmission fluid (ATF) temperature, e.g., induction motors with high temperature grade insulation. The reviewer thought the team may want to target such machines initially.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer declared that collaboration and coordination with various institutions are excellent, and noted that partnership with some end users have been clearly mentioned.

Reviewer 2:
It was clear to this reviewer that collaboration with other laboratories was occurring and the nature of the collaboration was also apparent. One example was the samples of windings from ORNL that simulated various gage sizes and fill factors. The reviewer anticipated that data from this experiment would be very interesting.

Reviewer 3:
The reviewer saw good collaboration between different institutions, but thought that more interaction with industry could be useful.

Reviewer 4:
The reviewer's analysis was that there is potential for increased collaboration, exchange of data/comparison with GE, the other group that is testing end winding impingement cooling. The reviewer suggested considering collaborating with universities as well, as they may be more open to sharing design information.

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 was glad to see the future work includes the bar wound stator study because most of the leading OEMs manufacturing traction motors are now using this technology. So NREL's efforts in this direction will be effective utilization of the DOE funding.

Reviewer 2:
The reviewer believed the proposed work is relevant and addresses some of the current gaps.

Reviewer 3:
The reviewer reported that decision points for selecting approach and focus were laid out very clearly in the presentation, along with milestones and go/no-go items. This person thought it was a clearly thought out plan.

Reviewer 4:
The reviewer agreed that the project was well planned and the future plan is clearly defined.

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

Reviewer 1:
The reviewer believed that thermal management is a key in terms of meeting the DOE targets for both the motor and power electronics

Reviewer 2:
The reviewer was of the opinion that improved thermal management is probably one of the biggest control knobs still available for significant increase in motor power density, assuming efficiency is still acceptable. This program can lead directly to improved electric powertrains that can help with petroleum displacement.

Reviewer 3:
The reviewer found that thermal considerations for motor design have a large effect on both cost and performance. Optimization of thermal performance and thermal management can have great effect.

Reviewer 4:
The reviewer stated that the work applies to both RE- and NRE- based motors. The reviewer speculated that if overall better thermal management leads to reduction of motor size while maintaining same power and efficiency, then it is likely to contribute to the objectives of petroleum displacement.

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

Reviewer 1:
This reviewer thought the resources are sufficient for the level effort

Reviewer 2:
The reviewer agreed that resources look sufficient.

Reviewer 3:
This reviewer's evaluation is that the capabilities for this experiment are easily met by the talent and resources at NREL.

Reviewer 4:
The reviewer concluded that resources indicated are reasonable.

Brushless and Permanent Magnet Free Wound Field Synchronous Motor (WFSM): David Ludois (University of Wisconsin-Madison) - edt065

Presenter

David Ludois, University of Wisconsin-Madison.

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 said that, given the short time of the project, the authors have done a good job in presenting the capacitive coupling for brushless wound field synchronous motor.

Reviewer 2:

The reviewer judged the approach to develop a motor to eliminate the need for RE permanent magnets to be an important and relevant objective. The implementation for capacitive power transfer is interesting, and as the project moves forward it will be beneficial to quantify the efficiency and cost relative to the DOE targets. The reviewer asked how the efficiency and cost of the proposed design compare with the DOE targets.

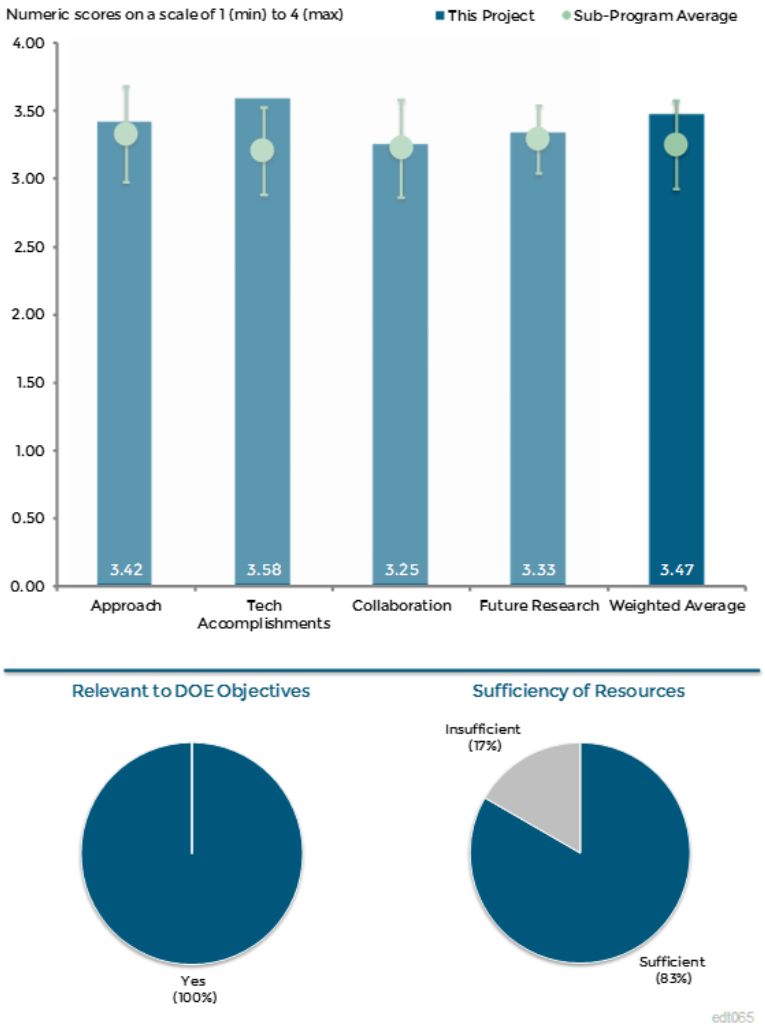

Figure 3-17 Brushless and Permanent Magnet Free Wound Field Synchronous Motor (WFSM): David Ludois (University of Wisconsin-Madison) - Electric Drive Technologies

Reviewer 3:

The reviewer found that the brushless capacitive transfer technique has some great advantages, but that there are several negatives associated with this approach, including the additional volume/reliability associated with the capacitive transfer plates, the cost/volume/reliability concerns associated with additional stationary circuitry and particularly the circuitry on the rotor. The reviewer stated that these are important issues to address for successful commercialization.

Reviewer 4:

The reviewer thought this project was especially refreshing to see because it was focused on one clear innovation. Whether this solves a real problem with wound field synchronous machines or not, the technology demonstrated here can open up new possibilities in electrical machine design. One concern this reviewer has is that it appears that a significant part of the effort is focused on demonstrating mature technology, at the risk of diluting efforts on the true innovation.

Reviewer 5:
The reviewer determined that technical barriers are more or less well defined, and that additional important barriers relate to the mechanical reliability of the capacitor coupling and also the amount of power transfer capability limits, without compromising safety. There seems to be some lack of integration with other efforts, in terms of coordinating with absolute end users, e.g., automotive and aerospace industry who could potentially benefit from the technology.

Reviewer 6:
The reviewer pointed out that the wound field synchronous motor (WFSM) has been used for many years in other markets, but adapting it to the automobile and truck market has merit. The reviewer thought that focusing on the capacitive power transfer (CPT) to enable WFSM relevance in the vehicle market was appropriate, and suggested that the packaging within the rotor to not impact overall motor length be a project mission.

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

Reviewer 1:
The reviewer said that the team has made excellent progress in the first 6-9 months of the project, coming up with the motor and capacitive coupling designs that look viable.

Reviewer 2:
The reviewer said that, considering this is a new start, a significant amount of accomplishments is not expected, but that considerable progress was made on several fronts on this project. The reviewer reported that great detail was provided regarding the modeling approach, and that detailed performance and efficiency estimates from simulation will be timely for future presentations.

Reviewer 3:
The reviewer conveyed that the work progress indicated has been completed as per timeline, which is compatible with the total timespan of the project. The reviewer qualified, however, that although desired focus at each year end has been indicated in a table, a comparison chart or bar graph showing the desired milestone versus accomplishment would have been better to understand the status.

Reviewer 4:
The reviewer recounted that the project just started, but design progress on the CPT is good. The CPT concept has some challenges that were discussed. The run out of the disks relative to the stator and rotor must be minimal. The reviewer thought that relying on a film at relatively low speeds may be problematic. The reviewer additionally recommended that the end play of the rotor relative to the stator needs to be minimized. The bearing design/choices need to allow for very little end-play, otherwise the disks will collide. The concern of shaft end play was not discussed. The reviewer further conveyed that the magnetic center of the rotor relative to the stator needs to relatively precise, otherwise the fields will tend to pull the shaft in a direction that will lead to collision of the disks.

Reviewer 5:
The project appeared to the reviewer to have demonstrated the capacitive coupling technique using gap pads and work is underway to implement it on a rotor. Information related to the expected efficiency of the proposed capacitive coupling technique would be of interest. Also, the expected impact on the motor efficiency would be important. The reviewer thought it would be nice to include the input and output voltage and current of the proposed design. The presentation mentioned the advantages at higher speed operation, but does the speed of the rotor have any impact on the power transfer. The reviewer concluded that work appeared to be progressing on the design of the motor.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer thought the collaboration and coordination with various institutions (i.e., academia and industry), are excellent, but that it would add more benefit if some coordination was also done with end users of the final product (e.g., automotive, aerospace, and other industries) who use electric motors in a complete system.

Reviewer 2:
The reviewer observed that the collaboration between universities appears strong, but additional collaborations with a motor supplier could be a benefit as the project moves forward.

Reviewer 3:
The reviewer reported that the collaboration between the two universities is good, but the relative roles of the universities is not clear.

Reviewer 4:
The reviewer said that the University of Wisconsin and Illinois Tech appear to be working well together, but thought there may be room for improvement in outreach to other entities with more experience in brushless and more conventional wound field synchronous machines.

Reviewer 5:
The reviewer suggested that additional collaboration with suppliers or OEMs may be advantageous for facilitating the technology-to-market process, and getting feedback with regards to feasibility.

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 future work appears to focus on developing the capacitive power coupling and the motor design, and that the plan allows for iteration of the design in the next year of work.

Reviewer 2:
The reviewer related that future plans entail several prototypes, and near term prototyping will help identify challenges associated with various new components used in this approach, allowing mitigation strategies to be developed at an early stage of the project.

Reviewer 3:
This reviewer thought the team has a good plan for demonstrating the technology being proposed. It was not clear from the presentation whether an adequate plan is in place to qualify the highest risk components of the project, specifically the brushless power transfer, before integrating it within the whole motor. Also, this reviewer suggested that to increase chances of success, the program office may consider reducing the requirements on the whole motor demonstration so unnecessary risk is not taken on the more standard parts of the motor design and build.

The reviewer also thought it would be good to see a comparison of the proposed method with other approaches, quantifying wherever possible; e.g., size, weight, cost, reliability, maintenance cycles, etc.

Reviewer 4:
The reviewer decided the proposed plan follows a good path, as the CPT is by far the highest risk element of the project and good focus has been put on the development. The reviewer suggested that alternative concepts or other approaches be considered to minimize/manage project risk.

Reviewer 5:
The reviewer appraised the project as well planned, and added a few additional issues that will add benefit: One, additional important barriers relate to the mechanical reliability of the capacitor coupling and also the amount of power transfer capability limits, without compromising safety. Two, manufacturing process for high volume production should also be thought ahead, because eventually that will be necessary. In addition, the issue of complexity of manufacture due to rotary capacitor and rotor winding, should be considered, along with cost ramifications. Three, more detailed references (patents, papers etc.) on existing work will be helpful.

Reviewer 6:
The reviewer stated that direct comparison of the inductive and capacitive coupling for this type of motor in terms of performance, cost, packaging and manufacturability will be great to be included in the next update.

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

Reviewer 1:
The reviewer reasoned that this project supports the DOE objectives to reduce petroleum because power dense and efficient motors that reduce the need for RE elements are important to reduce the cost of motors in vehicle applications.

Reviewer 2:
The reviewer reported that this project aims to develop alternatives to RE PM motors, and if successful, it will facilitate the electrification of powertrains by offering a motor design with more stable production cost.

Reviewer 3:
The reviewer reported it develops a low cost and power dense electric motor.

Reviewer 4:
Given that the key enabling technology within this program (the capacitive coupling) has possible applications even beyond brushless excitation of wound field synchronous machines, the reviewer believed that the project has potential to impact DOE objectives.

Reviewer 5:
The reviewer concluded that in the midterm to long-run it does meet DOE objectives, even though immediately it may not. Petroleum displacement may come about indirectly. It may not directly influence the petroleum displacement, because it is about replacement of the existing motors that use RE materials. If petroleum displacement in terms of vehicular fuel economy is considered, then it will not displace petroleum consumption. However, if the cost of getting RE material and its manufacturing process involves petroleum, then it may save fuel in an indirect manner.

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

Reviewer 1:
This reviewer reported that the funding level is low and the project is benefiting by using low cost students to get the work done.

Reviewer 2:
The reviewer stated that compared to the other projects within the same program office, it looks like this team is promising significant effort (i.e., design optimization, motor build, and test) for relatively lower program dollars. It did not appear to the reviewer that the team has allowed for iterative steps building on lessons learned during hardware demonstration.

Reviewer 3:
The reviewer said the resources appear to be sufficient.

Reviewer 4:
The reviewer conveyed that resources indicated are reasonable.

Traction Drive Systems with Integrated Wireless Charging: Gui-Jia Su (Oak Ridge National Laboratory) - edt066

Presenter

Gui-Jia Su, Oak Ridge National Laboratory.

Reviewer Sample Size

A total of three reviewers evaluated this project.

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

Reviewer 1:

The reviewer shared that although reduction of components (47%) is good, use of SiC and need for extensive infrastructure for inductive wireless charging may counterbalance the cost savings of the approach.

Reviewer 2:

This reviewer agreed with the approach to increase the efficiency of the wireless charging system through the use of WBG switches and improved coils and controls, but is not sure that integrating them within the traction electronics is the correct path. In the case of a PHEV the traction electronics may be located under hood where space is typically at a premium and any increase in size is an issue. Because the coils will be located under the vehicle the charging electronics may make more sense to be located near the pick-up coils or in the battery pack. The impact of integrating functions must be fully investigated to ensure that each individual function is not sub-optimized such as using the motor as part of the wireless charging function would probably eliminate the ability to charge while driving, which might be desirable in certain applications. The reviewer thought that combining the analog power module (APM) and charger in one unit is good as long as the charger does not impact the efficiency of the APM during motoring mode. The reviewer would suggest concentrating on that approach and let the traction system optimize itself, and asked if the ability to support bi-directional power flow from the charge function was a requirement.

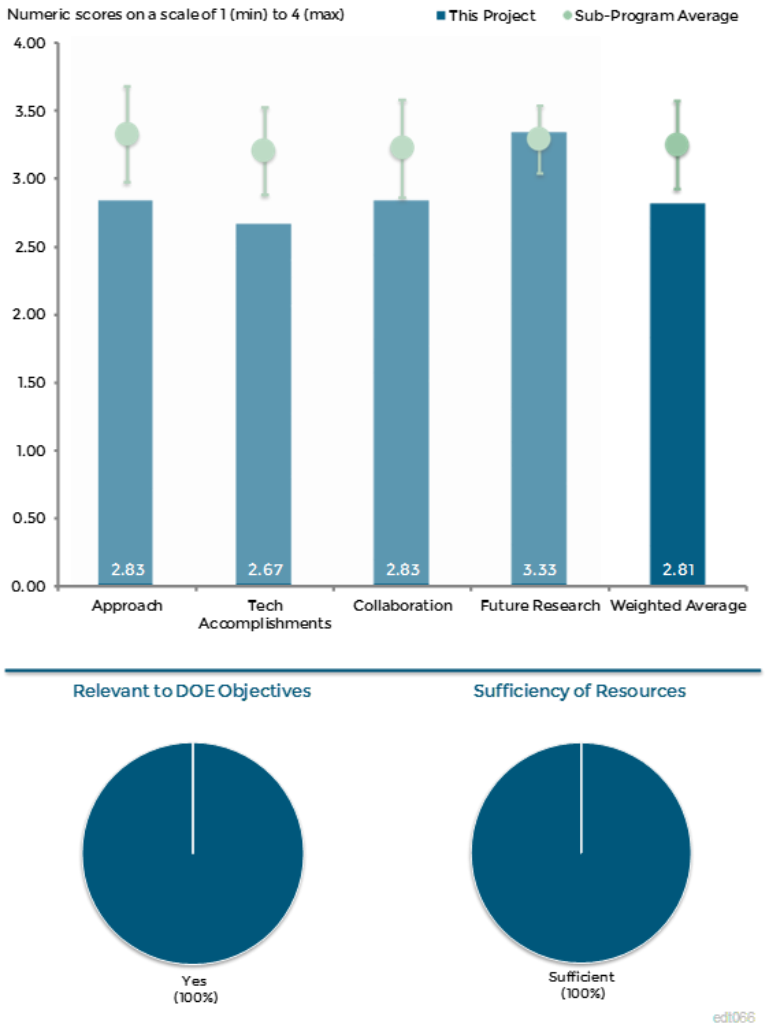

Figure 3-18 Traction Drive Systems with Integrated Wireless Charging: Gui-Jia Su (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 3:

The reviewer recommended the project team consider other impacts to the system when integrating functions. Should look at life of components given new duty cycle.

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

Reviewer 1:
The reviewer considered the progress to date to be very good for a new start building on past work. The optimized power factor for the resonant circuit is especially interesting and may have application elsewhere. The reviewer noticed that the efficiencies are provided for high loads but what happens at lower loads such as the more typical 30-40% 12 Volt loads in a vehicle. The second area of concern is using the motor neutral as this may not be as simple as thought, depending upon the motor winding process which may end up with the phase neutrals in different locations around the motor. The reviewer added that another issue is the cost of bringing another power lead out of a liquid filled motor/transmission combination, which requires a sealed connector arrangement. This reviewer concluded that the simulations look very good.

Reviewer 2:
The reviewer reported that the PI stated the literature review was completed and listed such as a major accomplishment, but did not present a single peer-reviewed publication reference. The reviewer suggested that the group recognize and reference previous related work from other groups and their own. The point of the literature review is to learn from previous research to guide the current research. This reviewer further pointed out that the PI stated that component and module models were built, but, no power quality numbers or harmonics were presented. The claim was made that power factor was high, and harmonics low, but no quantitative presentation of such was made.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer assessed that the team had a very good mix of component expertise which should supplement the circuit design expertise at ORNL, but did not see a vehicle integrator on the team, which will be necessary at some point to assist with integrating the system into a vehicle for demonstration purposes.

Reviewer 2:
The reviewer recognized that it may take some time to show integration and collaboration with partners, because this is a new start.

Reviewer 3:
The reviewer said it seemed that getting parts from the collaborators is most of what is being done, but did not have any information that shows real interaction with the collaborators is taking place.

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 though the team had a reasonable and logical step by step plan.

Reviewer 2:
The reviewer believed the planned future work was appropriate if the concerns mentioned above in the Approach section are addressed. Starting with a 3.3 kW and progressing to 6.6 kW is a good plan. The reviewer asked if the intent is to build a 6.6 kW power stage or parallel 2 3.3kW stages, and if the impact on efficiency if the input power is limited to 1 kW or 3.3 kW.

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

Reviewer 1:

The reviewer indicated that battery electric vehicles (BEVs) have potential to completely eliminate petroleum use, and that inductive charging may increase BEV market penetration and end use capabilities.

Reviewer 2:

The reviewer thought that a goal of improving the efficiency of wireless charging using improved coils, controls, and WBG devices is very relevant to the DOE goals but was not so sure that integrating them into the traction system is as relevant. That will be determined by the overall vehicle architecture.

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

Reviewer 1:

The reviewer concluded that resources are sufficient but that it might be advantageous to add a vehicle integrator or at least have access to a couple of them.

Reviewer 2:

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

Presenter

Charles Zhu, Delta Products Corporation.

Reviewer Sample Size

A total of four reviewers evaluated this project.

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

Reviewer 1:

The reviewer stated that this was a nice justification for the need and objectives of the program was presented, and thought that the presentation was a nice and brief technical description of the team's concept for integrating bi-directionality with on-board chargers (OBC) and reducing the number of switching devices was presented. The reviewer also thought it was a nice brief presentation of higher frequency benefits.

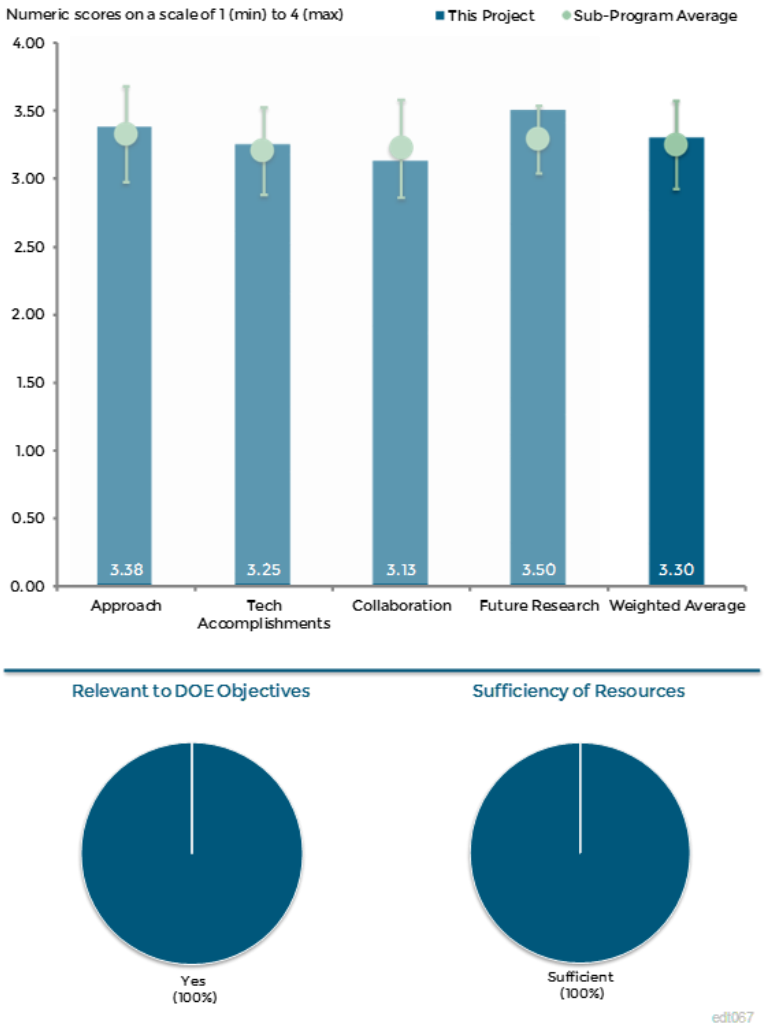

Figure 3-19 High-Efficiency High-Density GaN-Based 6.6 kW Bidirectional On-Board Charger for PEVs: Charles Zhu (Delta Products Corporation) - Electric Drive Technologies

Reviewer 2:

The reviewer found a clear understanding of what is needed for the application and how to investigate.

Reviewer 3:

The reviewer reported that this is a new project that will be using GaN devices in a bidirectional on board charger. The approach is to reduce the module size thus increasing power density and increase efficiency. The approach plans to take advantage of the switching speed of GaN devices as well as the lack of need for a separate freewheeling diode, which should allow for fewer devices and smaller magnetics, both of which will reduce the size of the unit. The high speed switching ability of GaN will allow a reduction in the size of the magnetics and other passives with in the unit. The reviewer found this approach would be reasonable if the GaN devices are able to perform as specified. The selected cascade GaN switch demonstrated good performance in supplier testing is appropriate for this use. The topology selected by Center for Power Electronics Systems (CPES) is based on an existing sine squared charger that also used early GaN switches that did not meet expectations and limited the power of the charger. The reviewer thought the design had potential and did provide insight into the size reduction potential and the issues with finding magnetics capable of meeting the needs at higher switching speeds. Plan A is based on a known topology and should meet the

performance goals assuming that the team can find magnetics/passives that will meet the requirements at high switching speeds and still meet the size requirements.

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

Reviewer 1:

The reviewer summarized that the accomplishments in a short time appear to be quite good, both with the experimental equipment tested and topologies investigated, and requirements for better magnetic and capacitor components. This reviewer reported that part of the charger concept prototypes was already built and tested. Test results so far are, however, incompletely demonstrated and should include quantitative analyses of power factor, efficiency, and harmonics. The reviewer further observed that the project team has so far tested only up to 3.3 kW and 150 kHz, which is very far from the objective 6.6 kW and 0.3 - 1.0 MHz.

Reviewer 2:

The reviewer thought progress was outstanding for a new program. The reviewer summarized that waveforms from the prototype look good and the operational modes of the DC/DC stage look good. The investigation into magnetic material has started as well as initial characterization of the selected GaN device. The operating frequency of the prototype stages is lower than the desired 300 kHz but very good for an initial test. Past experience with both Delta and CPES leads the reviewer to believe that this project will continue to make good progress and will meet the goals. The prototype charger appears to be based on air cooling of the devices, which is possible with the low switching losses of the GaN devices as demonstrated by the Trasnphorm boost testing but the reviewer thought that liquid cooling may be more beneficial for the final product if a more compact design is the goal. What was not discussed is the interface to the grid when the charger is providing power to the grid. This reviewer was not sure that today's charging standards define that mode or the control interface to be used. This may result in having to test the unit as a standalone DC/AC source or electric power takeoff (EPTO) to show the capability until the interface is defined.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer reported that this is a strong team in the areas of devices with Transphorm and circuit topologies and components with Delta and CPES. Fiat Chrysler Automobiles (FCA) brings vehicle integration experience. The results so far indicate that the technical members are working well together. The only item lacking is the interface to the grid interconnections which may be provided by FCA or another collaborator who has experience in supplying power to the grid. The reviewer believed that this is an industry opportunity that needs to be worked by the charger suppliers, vehicle OEMs, and utility companies to provide a standard interface if bi-directional chargers are to become a standard across the electric vehicle community.

Reviewer 2:

The reviewer said that because this is a new project not much collaboration was yet demonstrated, but expected this should improve in future years and must be better demonstrated in future years.

Reviewer 3:

The reviewer qualified that although understood Transphorm is key team member, and Infineon Si C7 superjunction MOSFET is key benchmark, it would be very interesting for the benchmark comparison to be expanded. The reviewer's suggestions are as follows: One, Infineon C7 superjunction – benchmark; two, Transphorm 650V field-effect transistor (FET); three, GaN Systems 650V FET; four, Cree 900V SiC MOSFET; five, Rohm 650V SiC trench MOSFET. The reviewer said that these parts are all widely available in catalog distribution (Mouser, etc.), so should be easily obtained, measured, and evaluated for modest cost and effort. The reviewer expected the result would be a much clearer picture of the WBG supply chain impact to OBC.

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

Reviewer 1:
The reviewer observed a good approach that is patterned after commercial development in the automotive industry was presented, and thought it was great.

Reviewer 2:
Other that institution collaboration, the reviewer thought that future research was very good.

Reviewer 3:
The reviewer found the proposed future research plan to be logical and well thought out. It continues the development of the device as well as the circuit topology allowing for optimization of both in parallel. The plan includes developing several versions of charger and switches as well as integrating with the vehicle and finally a commercialization plan to get this charger to the market. All of these items are required to successfully complete this task.

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

Reviewer 1:
The reviewer concluded that more compact and bidirectional charging is helpful to reduce petroleum use and increase PHEV market penetration.

Reviewer 2:
The reviewer declared that clearly cheaper, more efficient, and more power dense on-board chargers will lower the cost of EV.

Reviewer 3:
The reviewer pointed out that this project is one of a few that are not directed at motors or inverters. The OBC is an integral part of a BEV or PHEV and a bi-directional charger brings added capability to the vehicle. An added benefit of this project is an opportunity to further the development of GaN switches at a more realistic power level than trying to support high current level inverters from the beginning. The reviewer anticipated that it will allow the development of driving circuits as well as magnetic components.

Reviewer 4:
The reviewer reported that this project addresses bi-directional need for vehicle and grid.

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

Reviewer 1:
The reviewer found the team had adequate resources to meet the task at hand but may need to add a grid interface capability later.

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

Presenter

Nance Ericson, Oak Ridge National Laboratory.

Reviewer Sample Size

A total of four reviewers evaluated this project.

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

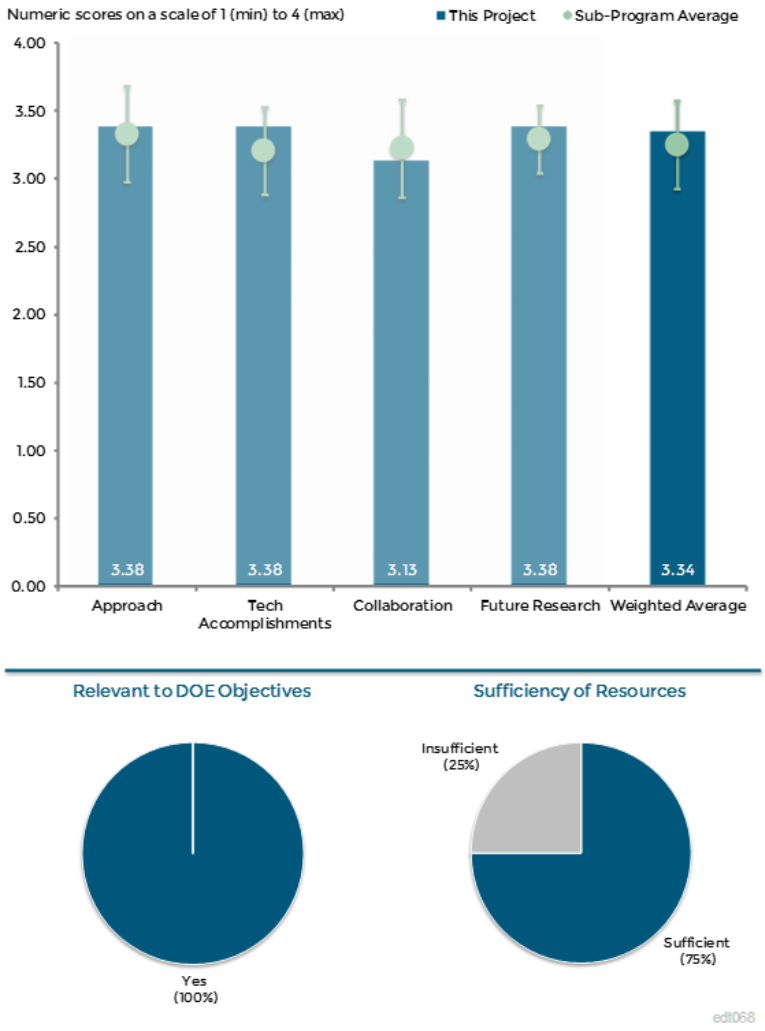

Figure 3-20 Gate Driver Optimization for WBG Applications: Nance Ericson (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 1:

The reviewer said that the development of a highly integrated gate drive capable of operating at high temperature and able to drive high power switching devices is sorely needed by inverter developers. While power modules have continued to shrink in size the gate drive circuitry has not and is now larger than the module driven in many cases. The goals listed in the presentation are a reasonable start at the requirements for a productized gate drive design. Building on work that has already been accomplished is good and allows the team to improve on that design where deemed necessary. This reviewer would like to see a review or solicitation added where the proposed functions are presented to various inverter implementers and comments requested with the intent of getting a broad set of requirements. Once this is done then the team can determine what makes sense to implement in a reasonably priced device. As mentioned above the requirements are a good start but fault modes need to be identified such as shoot through over current, shorts, bias supply issues, etc. The reviewer realizes that restraint needs to be applied to keep this chip from becoming the best gate drive device that nobody can afford.

Reviewer 2:

The reviewer agreed that a good justification for the research was presented.

Reviewer 3:

One concern this reviewer had with this project is what its aim is; for example, is it for the purpose of developing an understanding of what a systems integrator/designer needs to know or is it to get this gate driver produced. If to produce, then significant collaboration/partnerships would be needed for this to be successful.

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

Reviewer 1:
The reviewer reported that previous research was noted as an accomplishment. The reviewer thought it was quite a nice review of the literature with sufficient references to previous research and peer-reviewed publications. The project nicely presented some initial model results with some undesirable oscillations (thus far) which the reviewer considered a technical challenge. The reviewer disclosed that the fundamental contribution of closed-loop gate drive techniques was not sufficiently characterized and described, and asked what the key technical contribution of this approach was.

Reviewer 2:
The reviewer thought technical progress to date was excellent with all of the previous work that has been done. The proposed design is reasonable but the reviewer thought that there needs to be some input from potential users of the device. This person was not sure that a desaturation function will catch all over current faults and the reaction time for short circuit on the WBG devices is not well understood/specified at present. The sensing method for di/dt needs to be investigated for potential impact on accuracy and efficiency of the system. Typical failure modes that systems have trouble with are phase to phase shorts in the motor (low occurrence) where the di/dt is controlled by the inductance of the loop. Progress in the area of modeling WBG devices is needed as was discovered by the team – this should help industry as a whole if good spice models can be created. The reviewer concluded that the team has a good list of the challenges ahead and a plan to attack them, which should lead to a successful project.

Reviewer 3:
The reviewer declared the project team was just starting, but were making good progress so far.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that it seemed like the collaboration and relationship with the University of Tennessee is sound and well-established as presented throughout.

Reviewer 2:
The reviewer saw very good involvement with SiC device manufacturers, and proactive outreach to them for models and data.

Reviewer 3:
The reviewer believed that the team had a good selection of members in CREE and the University of Tennessee, but a device manufacturer and an inverter supplier were missing. Perhaps it is too early in the process for manufacturing input but the reviewer would suggest talking to one who has a gate driver for Si in production if possible. This person thought that the team might be able to take advantage of the Tech Team for user input on gate drive functions. It appeared to the reviewer that the existing team members are working well together.

Reviewer 4:
The reviewer stated that the team needed to widen engagement to have commercial power electronics providers engaged.

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 found this to be very necessary, important work. The point of high dv/dt and di/dt, is extremely salient given the strong performance of advanced SiC technology, and the very antiquated, high-inductance environments they often operate in. The reviewer concluded that users of SiC need to have good models, gate drivers, and tools to be able to utilize the new technology.

Reviewer 2:
The reviewer explained that the planned future work addresses previously discussed comments, which is good and perhaps occurs at a more appropriate time. This reviewer suggested that the engagement of OEMs should occur earlier rather than later but it need s to occur and is planned. The other tasks are in line with a well planned development process. One suggestion this reviewer had would be to add a review of the design requirements for the device prior to the fabrication of the first devices because it is an expensive process and the desire is to create a part that is as good as you get. The reviewer would also like to see an updated status of the critical assumptions and barrier as the project progresses.

Reviewer 3:
The reviewer recommended that the team should better show the path from prototype (use of off-shelf components for testing) to the integration of all of the technology into one integrated circuit.

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

Reviewer 1:
The reviewer thought a slide, "Improved Gate Drive Methods Are for Full Realization of Reliable WBG-Based Systems," stated the relevance of this project. For the DOE objectives to be met, WBG devices will be needed and these systems must be as reliable if not better than today's Si based systems.

Reviewer 2:
The reviewer appraised that the technology is necessary for enabled WBG power devices that can increase EV use.

Reviewer 3:
The reviewer pointed out that the project enables adoption of SiC on a wide scale, which is needed to push down the costs and time to market of SiC implementation. Faster adoption of SiC will lower power losses, lower size and weight of power electronics, and reduce the use of petroleum fuels in hybrid electric vehicles.

Reviewer 4:
The reviewer confirmed that this is necessary for WBG introduction to yield system benefits.

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

Reviewer 1:
The reviewer said that it seemed like the team could use additional funding to bring the technology to commercial reality.

Reviewer 2:
The reviewer determined that the resources are sufficient at the present time but input will be required from other resources as the project progress.

Power Electronics Thermal Management Research and Development: Kevin Bennion (National Renewable Energy Laboratory) - edt069

Presenter

Kevin Bennion, National Renewable Energy Laboratory.

Reviewer Sample Size

A total of three reviewers evaluated this project.

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

Reviewer 1:

The reviewer stated that the project provides fundamental understandings necessary for increasing power density and reducing cost.

Reviewer 2:

The reviewer considered thermal management of power electronics to be an important R&D topic that should be supported by DOE. This reviewer found a nice simple introduction of the heat transfer challenges and the relevance of the project, but thought it would be nice to include the management of heat flows through other components of the complete system (not just the inverter module) and heat generation in other components. Complex and quite geometry, materials, and design specific – should span a range of technology and design options.

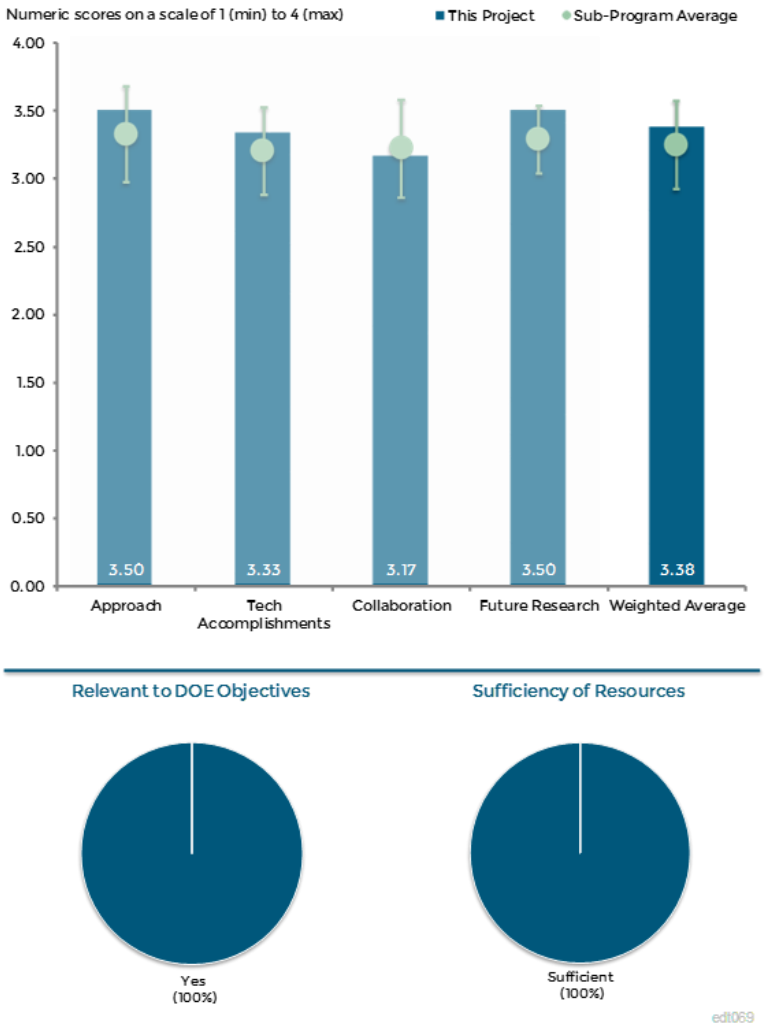

Figure 3-21 Power Electronics Thermal Management Research and Development: Kevin Bennion (National Renewable Energy Laboratory) - Electric Drive Technologies

Reviewer 3:

The reviewer revealed that the objective is to examine methods to get heat out of devise and control heat paths for systems using high temperature devices: both Si and WBG. The reviewer thought the team had a very good approach covering both high temperature Si and the newer WBG devices that are more efficient but smaller, which creates higher flux paths that need to be dealt width. Intent is to examine existing high density high power units for methods that were used and for areas that could be improved or enhanced. Alternative methods of cooling will be investigated including costs and manufacturing methods as well as performance. High temperature experience is provided by APREI. Initial approach will be based on thermal modeling using computer-aided design (CAD) models followed by static FEA model with a plan to use CFD if required – good approach. Good understanding of and creation of data needed to effectively model the system. The team has recognized the potential impact on the rest of the system as well as how integration at the system level may impact the power device thermal performance. The reviewer concluded that there is high potential for advances in thermal design with this project.

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

Reviewer 1:
The reviewer found that this is a new project with solid progress per their plan and approach. The presentation indicated a thorough understanding of a reasonable approach that would provide a high chance of success and that progress was being made along that plan. The reviewer judged the steps identified in the plan to be logical and reasonable and thought they should lead to a successful completion of the project. The plan includes looking at various thermal interface materials (TIMs) and thicknesses of them along with alternative cooling strategies such as air, different liquids, phase change materials, cold plate designs, etc., which is good but could take time and resources depending upon the availability and accuracy of existing models. The reviewer concluded that a reasonable amount of progress has been made to date but the next few months will determine if this project meets the reviewer's expectations.

Reviewer 2:
The reviewer stated that a literature search was listed as an accomplishment, but that Sato et al. 2011 was the only reference discussed along with some pictures from Tim Burress (ORNL) and Charlie King (NREL). This reviewer maintained that the literature review should be much more comprehensive.

The reviewer thought that selecting the Nissan LEAF inverter selected as a standard platform was okay and was presented as one of many that the work could apply to. The reviewer suggested the actual testing, simulation and evaluation of at least one other disparate system such as GM's Volt.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer reported that collaboration seems good, especially for a new start (2015) project. The reviewer expects that next year the team should be able to demonstrate how they actually worked together rather than just talking about getting CRADAs and non-disclosure agreements (NDAs) in place.

Reviewer 2:
The reviewer reported that the list of partners and team members shows a good mix of members with the appropriate skills and knowledge. At this point it is hard for this person to tell how well the team is working together but the plans and progress indicates that they are working well together. It is also encouraging to the reviewer to see that the team is actively trying to recruit new team members.

Reviewer 3:
The reviewer stated the team needs a vehicle manufacturer to ensure alignment with program objectives.

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 found the project considers all aspects of the system and its thermal issues and was happy to finally see a comprehensive look at what is going on and methods of addressing issues.

Reviewer 2:
The reviewer stated that the remaining challenges and barriers have been defined and the future work should address these challenges/barriers to some degree. This person believes that the team is disciplined enough to continue down the planned approach and not get detoured or slowed by spending too much time on approaches that do not show promise when modeled. Considering transient behavior is very important as is fault tolerance

to typical cooling system fault modes which should be added. The reviewer thought the plan for FY 2016 is good and it might be worthwhile to investigate means to move some of this into FY 2015 if possible without disturbing the team's progress.

Reviewer 3:

The reviewer suggested that the team should look at older inverters, not just new ones, because the grease degradation, increased Joule heating, corrosion, other worn parts, etc. may lead to significant heat management challenges that should be addressed.

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

Reviewer 1:

The reviewer maintained that this project is extremely relevant to the goals of the DOE in that it will help produce a reliable product that is compact, efficient, and affordable. The thermal performance has a huge impact on the size, cost, and reliability of the inverter and this project is addressing methods to improve that. It will be up to the manufacturer to determine which approach to take but knowing what the performance will be will allow them to select the best approach for their product and one that will work in their manufacturing processes.

Reviewer 2:

The reviewer believes it is very important to consider and better design thermal management systems for inverter/converter systems and too little attention is typically paid to these very important aspects of working systems. This is a key enabling technology for introducing more EV technology.

Reviewer 3:

The reviewer cited fundamental understanding necessary for improving density and cost.

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

Reviewer 1:

The reviewer said the resources to date appear to be sufficient but more data on modeling support will be required to determine if it is actually sufficient.

Thermal Performance Benchmarking: Gilbert Moreno (National Renewable Energy Laboratory) - edt070

Presenter

Gilbert Moreno, National Renewable Energy Laboratory.

Reviewer Sample Size

A total of five reviewers evaluated this project.

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

Reviewer 1:

The reviewer thought NREL and ORNL collaboration pathway with industries was appropriate, relevant and could address industry's needs, and summarized that electric motor and power converter thermal management approach is outlined, and test platforms of Nissan LEAF motor, Honda Accord inverter, and auxiliary components are identified.

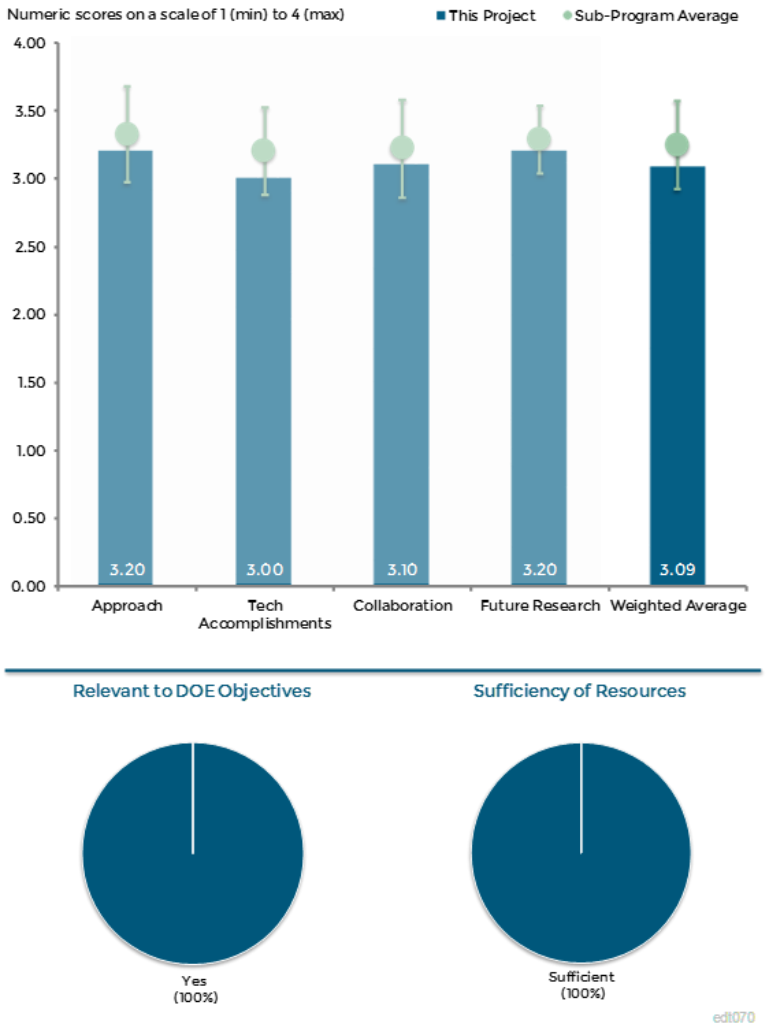

Figure 3-22 Thermal Performance Benchmarking: Gilbert Moreno (National Renewable Energy Laboratory) - Electric Drive Technologies

Reviewer 2:

The reviewer stated that thermal benchmarking sets a baseline for evaluating improvements in future designs

Reviewer 3:

The reviewer found it was early in the project but thought it seemed designed well and compliments the ORNL EV and HEV Benchmarking project (edt006).

Reviewer 4:

The reviewer thought a plan was needed to quantify or evaluate the test error compared to real operating conditions.

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

Reviewer 1:

The reviewer found there was mostly planning with some early benchmarking performed so far because it is so early in the project, but that the team had accomplished what had been planned to accomplish.

Reviewer 2:
The reviewer saw that progress was being made, but was not sure how valuable data generated will be, because thermal data tends to be very specific for a particular solution.

Reviewer 3:
The reviewer reported that the project is a new start and work is progressing; the parts being evaluated are new parts but the vehicles they go into have been on the road for a couple of years. The reviewer wondered if it was possible to get some used parts with many miles on them to use for the benchmarking evaluations. The reviewer thought it would be easy to go back to create the ideal initial structure to see if the model predicts the current state of degradation of the used power electronics, and that would provide more validity to the model.

Reviewer 4:
The reviewer summarized that the motor is instrumented for development of a temperature map. Temperature map is used to develop thermal resistance data for various key points/locations in electric motor. Motor CAD drawing is developed. Only copper losses or thermal load due to copper losses are considered in the motor, when iron losses are also incepted, heat flow path could be altered resulting in different values of thermal resistances. This may need adjustment of thermal resistance map and values of thermal resistances.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer stated that ORNL and ANL are suggested as collaborators in this project.

Reviewer 2:
The reviewer held that some industry participation would be welcomed, but saw good communication between ORNL and NREL.

Reviewer 3:
The reviewer commented that the results of the benchmarking can be used by ORNL and ANL to evaluate improvements to the design that may be applicable to other applications.

Reviewer 4:
This reviewer suggested trying to engage an 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 thought the next steps were logical, saw no real technical barriers, and said just execute.

Reviewer 2:
The reviewer reported that the method to identify performance of an oil cooled 2014 Honda Accord is suggested as one of the future research tasks.

Reviewer 3:
The reviewer relayed that the team was working to a plan to benchmark motors and inverter thermal performance.

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

Reviewer 1:
The reviewer reasoned that this project has potential outcome to increase thermal performance of the electric motor and power converter, which supports DOE objectives.

Reviewer 2:
The reviewer maintained that improving the thermal performance of power electronics helps to identify ways to reduce the costs of power electronics, which helps to enable the market for EDVs which reduces our dependence on foreign oil.

Reviewer 3:
The reviewer thought that perhaps the project is not a direct contributor to reduced petroleum dependence because it is a benchmarking project. However, the reviewer predicted that it would indirectly contribute by assisting the industry in educating best (and worst) practices and new/novel techniques

Reviewer 4:
The reviewer saw that this project has value, but was concerned that thermal tends to be very specific to a system, and with the timeliness of the information generated.

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

Reviewer 1:
The reviewer thought that human resources are adequate, but that the $200,000 funding seemed light for the work planned

Multi-Speed Range Electric Motor Research and Development: Lixin Tang (Oak Ridge National Laboratory) - edt071

Presenter

Lixin Tang, Oak Ridge National Laboratory.

Reviewer Sample Size

A total of five reviewers evaluated this project.

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

Reviewer 1:

The reviewer predicted that the project has a high likelihood of success through use of purchasing motors with six wire outputs and solid state switches, and agreed that cost/complexity optimization through minimization of the number of solid state switches to accomplish the performance/efficiency goals while maintaining proper system protections is good.

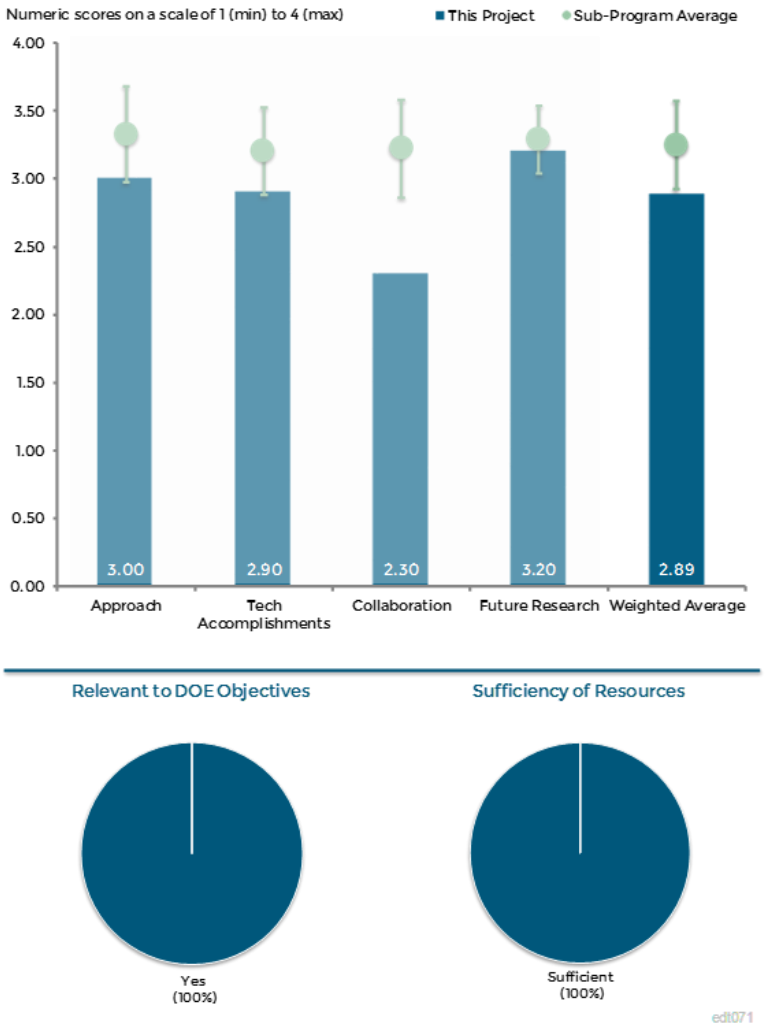

Figure 3-23 Multi-Speed Range Electric Motor Research and Development: Lixin Tang (Oak Ridge National Laboratory) - Electric Drive Technologies

Reviewer 2:

The reviewer stated that, generally, benefits of re-configurable windings are well known, but that the problem is the practical implementation of such concepts due to requirement of additional switches, torque interruptions and potential circulating current. The reviewer concluded that system level understanding is critical in evaluating the benefits of such concept.

Reviewer 3:

The reviewer concluded that technical barriers have been defined clearly. The barriers indicated in the beginning relate to consequence of not pursuing multi speed range motor R&D. Later on additional barriers related to extra complexity of the system have been detailed. All of these are relevant challenges. There seemed to this reviewer to be some lack of integration with other efforts, in terms of coordinating with absolute end users, e.g., automotive and aerospace industry who could potentially benefit from the technology. The reviewer concluded that the PI has indicated the intention to investigate such possibilities and given that it is a new project, it is understandable that this might take some time.

Reviewer 4:
The reviewer revealed that the high-level idea of changing motor speed range is not novel by itself, as pointed out by the PI, but there were not enough details about how the proposed approach is better than the state of the art.

Reviewer 5:
The reviewer found that the work reported showed the benefits of using reconfigurable windings for motor operation in wide speed range. This validates what is known in the art about the advantages of changing the winding configurations in series-parallel combinations to obtain constant torque from minimum to maximum speed without exceeding drive voltage limits. The challenge has been the trade-off of complexity and cost with the potential benefits. The reviewer reported that the team appeared to be focused on this challenge, but details of the new approach have not been shared.

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

Reviewer 1:
The reviewer concluded that the technical accomplishments are very good to date. The reviewer found the expanded motor performance plots are very instructive on what can be accomplished through switching.

Reviewer 2:
The reviewer stated that the PI appears to have come up with a new concept to implement the winding reconfiguration with fewer switches, which may make the trade-off between benefits and added complexity/cost more favorable. However, the new concept is not described in the poster/uploaded material, nor shared during the poster presentation making assessment of the technical accomplishments hard to do.

Reviewer 3:
The reviewer reported that work is about 17% complete, which is reasonable in terms of the total time span of the project, given that the work was started in FY 2015.

Reviewer 4:
The reviewer found the project hard to judge because the project is new and aside from some high-level simulations, there were not enough details

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer reported a new project and no partners at the moment.

Reviewer 2:
The reviewer said that it does not look like any collaboration has been set up yet. It would be useful to reach out to an industry partner to understand relative costs of motor, inverter, and the switches needed for the proposed concept in order to perform a thorough trade-off of study.

Reviewer 3:
The reviewer pointed out that this is a small project. While the grade is poor, this person suggested that it remain a focused small project, otherwise the funding and scope should be revisited.

Reviewer 4:
The reviewer suggested that collaboration and coordination with various institutions, i.e., academia and industry, could be further extended. In particular, it would add more benefit if some coordination was also done with end users of the final product, e.g. automotive, aerospace, and other industries, who use electric motors in

a complete system. Because this is new project, the reviewer understood that further collaboration will take some additional time to be in place.

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 saw good proposed future work but more details about the approach are needed.

Reviewer 2:
The reviewer found the future plan to be satisfactory, but encouraged the team to also include a more rigorous benefit/cost analysis of the whole system, and to learn from past efforts by others.

The reviewer recommended that the team select a real baseline design to use as a benchmark and compare costs of implementing the new approach, with the new switches and any added costs to the motor in bringing more leads out of the motor to where the new switches will be mounted. Share a comparison to alternate system level approaches.

Reviewer 3:
The reviewer thought the project was well planned, but listed a few additional issues which will add benefit: One, the project will be very beneficial towards overall system efficiency increase. System level studies are very important and the effort is highly commended for that. Two, exact methodology for multi-speed range is not clearly indicated. It appears that PI has some patents etc. in the process, which might not allow at this time to describe details. Three, more detailed references, such as patents, papers etc., on existing work will be helpful, although some patents have been cited.

Reviewer 4:
The reviewer thought the proposed future scope should take the project to a paper and/or patent application.

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

Reviewer 1:
The reviewer reasoned that the project enables much lower cost motor topologies such as induction to gain more relevance in EVs, HEVs, and PHEVs by dramatically increasing the motor's performance/efficiency curve.

Reviewer 2:
The reviewer clarified that the project relates to system level efficiency increase, and will therefore lead to better fuel efficiency and hence lead to the objectives of petroleum displacement.

Reviewer 3:
The reviewer said that if successful, increasing the efficiency over the drive cycle is important to meet the DOE targets

Reviewer 4:
The reviewer speculated that if successful, the team would have developed a motor-drive system that is better suited for a wide speed range without compromising on performance.

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

Reviewer 1:
This reviewer thought the resources are sufficient for the level of effort

Reviewer 2:
The reviewer found the resources indicated to be reasonable.

Reviewer 3:
The reviewer stated that, provided that the scope does not change, the funding is sufficient.

30 kW Modular DC-DC System using Superjunction MOSFETs: Robert Erickson (University of Colorado) - edt072

Presenter

Robert Erickson, University of Colorado.

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 thought the proposed architecture appears to have great potential, and was interested in seeing the system implemented in as-built hardware.

Reviewer 2:

The reviewer said that the approach is thoughtful and unique compared to others the reviewer has seen done.

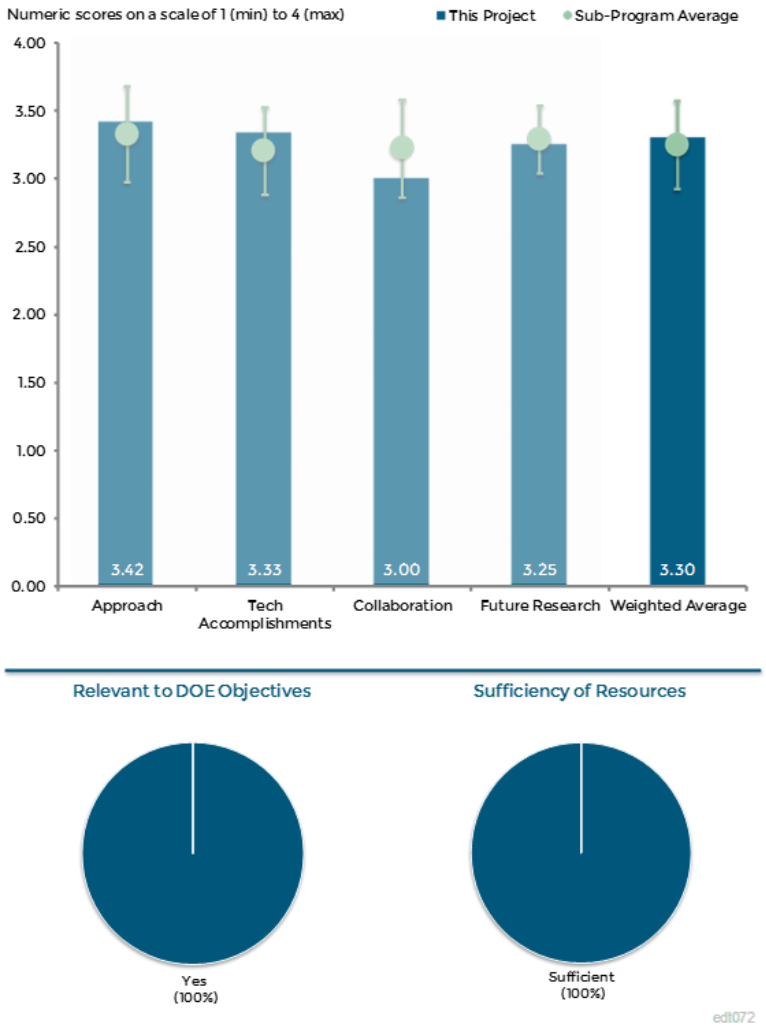

Figure 3-24 30 kW Modular DC-DC System using Superjunction MOSFETs: Robert Erickson (University of Colorado) - Electric Drive Technologies

Reviewer 3:

The reviewer considered this a thoughtful approach and a well-designed project, and stated that the goals are clear and objectively evaluable.

Reviewer 4:

The reviewer reported the project is very focused on a high efficiency DC-DC converter(s) with integrated charger. The reviewer declared it was a novel approach.

Reviewer 5:

The reviewer relayed that a composite converter topology is planned to be investigated to assess advantages such as efficiency improvements, film capacitor size reduction, and on-board charger size reduction.

Reviewer 6:

The reviewer thought the proposed approach (Buck + DCX) seemed to require more silicon switches and magnetics, which would contradict the high power density 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 towards DOE goals.

Reviewer 1:
The reviewer said that for this new start project the proposed architecture simulation results are encouraging.

Reviewer 2:
The reviewer agreed that this was a good start with lots of earlier simulation results looking good.

Reviewer 3:
The reviewer would be interested to see what the other considered topologies were and their related efficiencies, because the PIs commented that four architectures were considered, and the team settled on the presented approach.

Reviewer 4:
The reviewer reported that output power versus efficiency curve was obtained and an operating regime of DC bus voltage for maximum efficiency was identified.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer thought the roles of the various partners seemed well defined.

Reviewer 2:
The reviewer maintained that the existing project partnerships and collaborators were good, but that the team would be stronger with a systems integrator or OEM because the ultimate results will manifest themselves only through systems (drive-cycle) comparisons

Reviewer 3:
The reviewer reported that APEI is subcontractor for WBG power devices and APEI module picture is shown in the report. GE as SiC MOSFET supplier and Infineon as GaN FETs.

Reviewer 4:
The reviewer suggested that it would be useful to have a Tier 1 or OEM involved to evaluate the work and look at the economics of the approach as well as the overhead of the control strategies that would be involved with this system. The reviewer thought that from the technical side collaboration and coordination was excellent.

Reviewer 5:
The reviewer thought the team really needs a vehicle manufacture and national laboratories 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 found it to be well focused on the technical barriers

Reviewer 2:
This reviewer was looking forward to seeing the hardware.

Reviewer 3:
The reviewer judged the remainder of project to be well architected. The reviewer was not sure about the on-board charger relevance to the program, but considered it a bonus add-on.

Reviewer 4:
This reviewer reported that key tasks for future research are proposed.

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

Reviewer 1:
The reviewer determined that the efficiency increase and size and weight reductions are aligned with DOE-APEEM targets

Reviewer 2:
The reviewer thought it addresses how to optimize best for efficiency.

Reviewer 3:
This reviewer found this approach helps to lower the cost of EDV power electronics, which helps to enable the markets for EDVs, which reduces our dependence on foreign oil.

Reviewer 4:
The reviewer resolved that this was a novel approach to support DOE objectives.

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

Reviewer 1:
The reviewer thought resources were sufficient for the technical barriers, but that they may need some help from a Tier 1 or OEM for the cost targets.

Reviewer 2:
The reviewer agreed that resources and funding appeared sufficient

Evaluation of an APEI 88 kW SiC Inverter with Next-Generation Cree 900 V SiC MOSFET Technology for Ford Automotive Systems: Jeffrey Casady (Cree, Inc.) - edt073

Presenter

Jeffrey Casady, Cree, Inc.

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 thought the objectives (i.e., AEC Q101 qualification) and approach appeared reasonable.

Reviewer 2:

The reviewer determined that the project goals were clearly based on the DOE targets, although the impact of the project seemed slightly limited. It looked to the reviewer like a key contribution is to drive down cost, but that further evaluation of the approach depends on the system architecture moving forward.

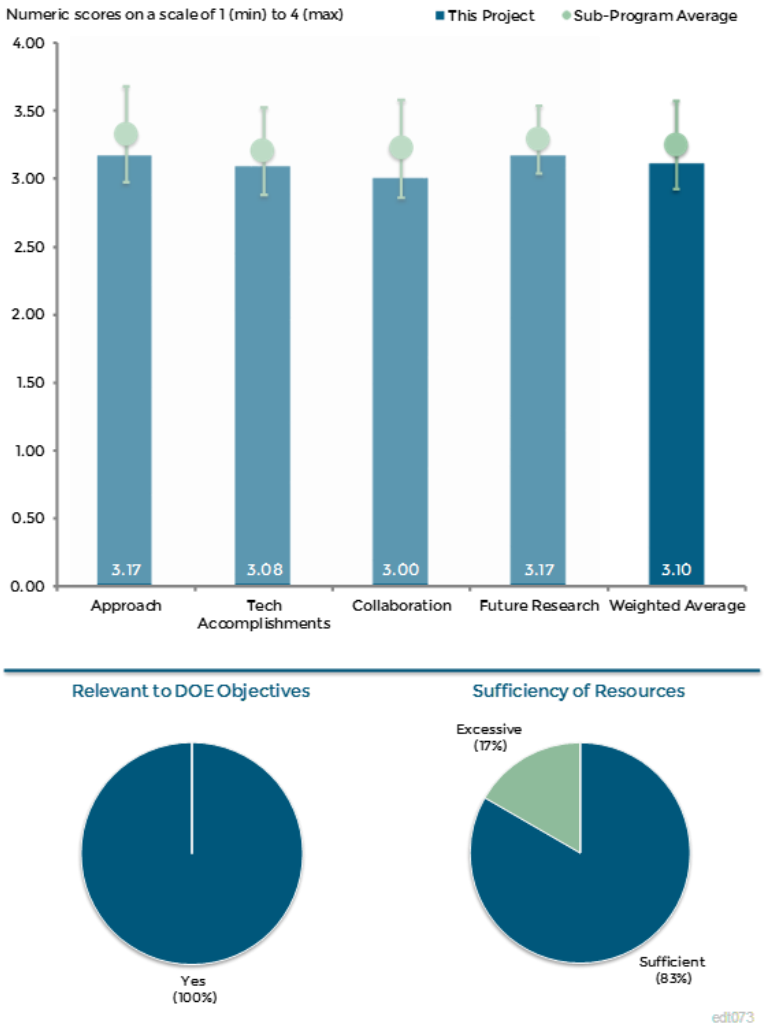

Figure 3-25 Evaluation of an APEI 88 kW SiC Inverter with Next-Generation Cree 900 V SiC MOSFET Technology for Ford Automotive Systems: Jeffrey Casady (Cree, Inc.) - Electric Drive Technologies

Reviewer 3:

The reviewer reported that Cree has a plan to enable and qualify their SiC MOSFET, in a TO-247 package, for future automotive applications. There is a plan to qualify the part in a module but no details are given; the reviewer asked if that detail could be disclosed.

Reviewer 4:

The reviewer relayed that project tasks are focused for design and development of 900V SiC MOSFET followed by development of 900V SiC half bridge and then demo of these devices in 88kW traction drive.

Reviewer 5:

The reviewer was not sure if this is appropriate work for DOE, because it seemed to be just about qualifying and demonstrating a part.

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

Reviewer 1:
It appeared to the reviewer that the device is ready for the next stage in terms of packaging and device integration. Further evaluation of the results depends on the architecture and system performance moving forward. The reviewer asked about how, specifically, the device design impacts the projected cost target.

Reviewer 2:
The reviewer found that new start test data on the die is becoming available, and that multiple iterations of the die seem to be planned.

Reviewer 3:
The reviewer considered this to be adequate for this early in the project.

Reviewer 4:
The reviewer reported that RDS on resistance versus temperature data is characterized. Energy loss data shows that as compared to Silicon MOSFET, SiC MOSFET is 4 times better at 25°C and 6 times better at 150°C. This proves advantage of WBG material and encourages designers to use this material in power converter designs.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer assessed that the roles of the various project partners were clear.

Reviewer 2:
The reviewer reported that the implication was OEMs are evaluating inverters that are using Cree's MOSFET for future inverter projects.

Reviewer 3:
The partners on this project are what the reviewer would have wanted to see; semiconductor, packaging, and OEM. This reviewer was not sure how well they are working together.

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

Reviewer 1:
The reviewer determined that the path forward seemed clear, although the details of the final system application are somewhat limited. The reviewer thought that early estimations of the projected cost of the system will be beneficial in determining the effectiveness of the proposed path.

Reviewer 2:
The reviewer reported that there is a test plan for the chip, the chip in packages, and the packages in inverters.

Reviewer 3:
The reviewer revealed that a set of tasks are proposed as future research.

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

Reviewer 1:
The reviewer ascertained that lowering the cost, size and weight of automotive power electronics helps to enable the markets for EDVs, which helps to reduce our dependence on foreign oil.

Reviewer 2:
The reviewer resolved that all of the WBG projects have the potential to lower our dependency on petroleum. These projects have high risk, high cost development, and high reward potential.

Reviewer 3:
The reviewer judged that the objectives are aligned to achieve DOE APEEM targets

Reviewer 4:
The reviewer stated that SiC devices are more efficient and if qualified for automotive should help address DOE targets.

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

Reviewer 1:
The reviewer was unsure about human resource sufficiency, but said the funding appeared to be more than adequate to accomplish the project goals.

Acronyms and Abbreviations

Acronym	Definition
3-D	Three-dimensional
AEC	Automotive Electronics Council
Al	Aluminum
AMR	Annual Merit Review
ANL	Argonne National Laboratory
APEEM	Advanced Power Electronics and Electrical Machines
APM	Analog power module
ATF	Automatic transmission fluid
BIM	Bonded interface material
CAD	Computer-aided design
CAFE	Corporate average fuel economy
CFD	Computational fluid dynamics
Co	Cobalt
CO2	Carbon dioxide
CPES	Center for Power Electronics Systems
CPT	Capacitive power transfer
CTE	Coefficient of thermal expansion
CY	Calendar year
DBC	Direct bonded copper
DC	Direct current
DOE	Department of Energy
Dy	Dysprosium
EDV	Electric Drive Vehicle
EETT	Electrical and Electronics Technical Team
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference

EPTO	Electric power takeoff
ESL	Equivalent series inductance
ESR	Equivalent series resistance
EU	European Union
EV	Electric Vehicle
Fe	Iron
FEA	Finite element analysis
FET	Field-effect transistor
FOA	Funding Opportunity Announcement
FY	Fiscal year
GaN	Gallium Nitride
GE	General Electric
GM	General Motors
HcJ	Thermal coefficient of coercive force
HEV	Hybrid electric vehicle
HV	High-voltage
IGBT	Insulated-gate bipolar transistors
IPM	Integrated permanent magnet
ISMG	integrated starter motor generators
kW	Kilowatt
kV	Kilovolt
MGOe	Megagauss-oersteds
MLCC	Multilayer ceramic capacitor
MOSFET	Metal–oxide–semiconductor field-effect transistor
MPG	Miles per gallon
MPGe	Miles per gallon-electric
Nd	Neodymium
Ni	Nickel

NRE	Non-rare earth
NREL	National Renewable Energy Laboratory
OBC	On-board charger
Oe	Oersteds
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
PBA	Planar bond-all
PCB	Printed circuit boards
PEI	Polyetherimide
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
PI	Principal investigator
PLZT	Lead lanthanum zirconate titanate
PM	Permanent magnet
PML	Polymer-multi-layer
PMSM	Permanent magnet synchronous motor
R&D	Research and development
RE	Rare earth
RPM	Rotations per minute
Si	Silicon
SiC	Silicon carbon
SOA	State of the art
TIM	Thermal interface materials
V	Volt
VTO	Vehicle Technologies Office
WBG	Wide bandgap
WFSM	Wound field synchronous motor
xEV	Electric vehicle (all configurations)

Zn	Zinc