3. Power Electronics and Electrical Machines Technologies

Advanced technology vehicles such as hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), fuel cell hybrid electric vehicles (FCHEVs), and electric vehicles (EVs), require power electronics and electrical machines (PEEM) to function. These devices allow the vehicle to use energy from the battery to assist in the propulsion of the vehicle, either on their own or in combination with an engine. Advanced electric drive vehicles can help meet important DOE goals, such as petroleum reduction. However, modern day PEEM technology is not sufficient to enable market-viable PHEVs, FCHEVs, and EVs. The Vehicle Technologies Program aims to develop these technologies by setting strategic goals for PEEM, and undertaking research projects that are carried out through collaboration among government, national laboratories, academia, and industry partners. Achieving the PEEM goals will require the development of new technologies. These new technologies must be compatible with high-volume manufacturing and must ensure high reliability, efficiency, and ruggedness. These technologies must also reduce cost, weight, and volume. Of all these challenges, cost is the greatest. PEEM project partners work together to ensure that technical attributes, vehicle-scale manufacturing, and cost sensitivities are addressed in a timely fashion and that the resulting technologies can be adopted by companies willing and able to supply products to automakers.

In August 2009, the Department announced the selection of ten projects totaling $495 million that will help accelerate the establishment of a globally competitive, domestic infrastructure for advanced electric drive vehicle manufacturing. ARRA-funded Power Electronics and Electrical Machines Technologies activities support programs to enable production and commercialization of advanced electric drive vehicles, which help to reduce petroleum consumption. Activities include developing low-cost electric propulsion systems; supporting an increase in production capacities for electric drive components, manufacturing plants, and parallel hybrid propulsion systems; and supporting development of electric drive semiconductors. Additionally, AARA-funded activities that support commercialization include accelerating the launch of HEVs/PHEVs through efforts including localizing the design and production of transaxle systems, and developing a lower-cost, higher-control standardized platform. These ARRA-funded projects were not evaluated during the 2011 AMR. The remainder of the Power Electronics and Electrical Machines Technologies activities that have been funded for FY 2011, however, were reviewed in the 2011 AMR.

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 to 4)*. 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 summary 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
Inverter Using Current Source Topology	Su, Gui-Jia (Oak Ridge National Laboratory)	3-3	3.40	3.20	3.20	3.40	3.28
A Segmented Drive Inverter Topology with a Small DC Bus Capacitor	Su, Gui-Jia (Oak Ridge National Laboratory)	3-5	3.00	3.17	2.67	2.83	3.02
Novel Flux Coupling Machine without Permanent Magnets	Hsu, John (Oak Ridge National Laboratory)	3-7	2.75	2.50	2.25	3.00	2.59
Benchmarking of Competitive Technologies	Burress, Tim (Oak Ridge National Laboratory)	3-9	3.50	3.67	3.00	3.17	3.48
Wide Bandgap Materials	Chinthavali, Madhu (Oak Ridge National Laboratory)	3-11	3.20	3.20	3.40	3.40	3.25
High Dialectric Constant Capacitors for Power Electronic Systems	Balachandran, Uthamalingam (Argonne National Laboratory)	3-14	3.00	3.25	3.50	3.25	3.22
High Temperature Polymer Capacitor Dielectric Films	Dirk, Shawn (Sandia National Laboratories)	3-16	3.50	3.25	3.25	3.50	3.34
Glass Ceramic Dielectrics for DC Bus Capacitors	*Lanagan, Michael (Pennsylvania State University)*	*3-18*	*3.00*	*3.00*	*3.00*	*3.00*	*3.00*

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Development, Test and Demonstration of a Cost-Effective, Compact, Light-Weight, and Scalable High Temperature Inverter for HEVs, PHEVs, and FCVs	Taylor, Ralph (Delphi Automotive Systems)	3-20	3.25	2.75	3.50	2.75	2.97
Scalable, Low-Cost, High Performance IPM Motor for Hybrid Vehicles	El-Refaie, Ayman (General Electric Global)	3-22	3.00	2.75	3.25	3.00	2.91
Advanced Integrated Electric Traction System	Smith, Greg (General Motors)	3-24	3.50	3.50	3.25	3.00	3.41
Permanent Magnet Development for Automotive Traction Motors	Anderson, Iver (Ames)	3-26	3.20	3.20	3.40	3.40	3.25
Air Cooling Technology for Power Electronic Thermal Control	Lustbader, Jason (National Renewable Energy Laboratory)	3-28	3.60	3.20	3.40	3.60	3.38
A New Class of Switched Reluctance Motors without Permanent Magnets	Burress, Tim (Oak Ridge National Laboratory)	3-30	3.17	3.17	2.50	2.83	3.04
Power Device Packaging	*Liang, Zhenxian (Oak Ridge National Laboratory)*	*3-32*	*3.25*	*3.25*	*3.00*	*3.25*	*3.22*
High Power Density Integrated Traction Machine Drive	Wang, Fei (Oak Ridge National Laboratory)	3-34	2.67	2.67	2.67	3.00	2.71
Electro-thermal-mechanical Simulation and Reliability for Plug-in Vehicle Converters and Inverters	*Hefner, Allen (National Institute of Standards and Technology)*	*3-36*	*3.67*	*3.67*	*3.33*	*3.67*	*3.63*
Development of SiC Large Tapered Crystal Growth	Neudeck, Philip (National Aeronautics and Space Administration)	3-38	3.00	2.75	3.00	3.00	2.88
Thermal Performance and Reliability of Bonded Interfaces	Narumanchi, Sreekant (National Renewable Energy Laboratory)	3-40	3.40	3.00	3.20	3.20	3.15
Electric Motor Thermal Management	Bennion, Kevin (National Renewable Energy Laboratory)	3-42	3.20	2.60	3.00	2.80	2.83
Inverter Cost Analysis and Marketing Intelligence	Whaling, Christopher (Synthesis Partners)	3-44	2.67	2.40	3.20	2.20	2.54
Converter Topologies for Wired and Wireless Battery Chargers	Su, Gui-Jia (Oak Ridge National Laboratory)	3-46	3.00	3.20	3.20	3.20	3.15
Integration of Novel Flux Coupling Motor and Current Source Inverter	*Hsu, John (Oak Ridge National Laboratory)*	*3-48*	*2.33*	*2.33*	*2.33*	*2.67*	*2.38*
Motor Packaging with Consideration of Electromagnetic and Material Characteristics	*Miller, John (Oak Ridge National Laboratory)*	*3-50*	*3.00*	*2.50*	*2.75*	*3.00*	*2.72*
Physics of Failure of Electrical Interconnects	*DeVoto, Doug (National Renewable Energy Laboratory)*	*3-52*	*3.25*	*3.50*	*3.00*	*3.25*	*3.34*
Two-Phase Cooling Technology for Power Electronics with Novel Coolants	Moreno, Gilbert (National Renewable Energy Laboratory)	3-54	3.20	3.20	3.20	2.80	3.15
Integrated Vehicle Thermal Management â€“ Combining Fluid Loops in Electric Drive Vehicles	Rugh, John (National Renewable Energy Laboratory)	3-56	3.40	3.20	3.00	3.40	3.25
Compact, Light-Weight, Single-Phase, Liquid-Cooled Cold Plate	*Narumanchi, Sreekant (National Renewable Energy Laboratory)*	*3-58*	*3.00*	*3.40*	*3.00*	*3.00*	*3.20*
Overall Average			3.15	3.05	3.05	3.09	3.08

Note: Italics denote poster presentations.

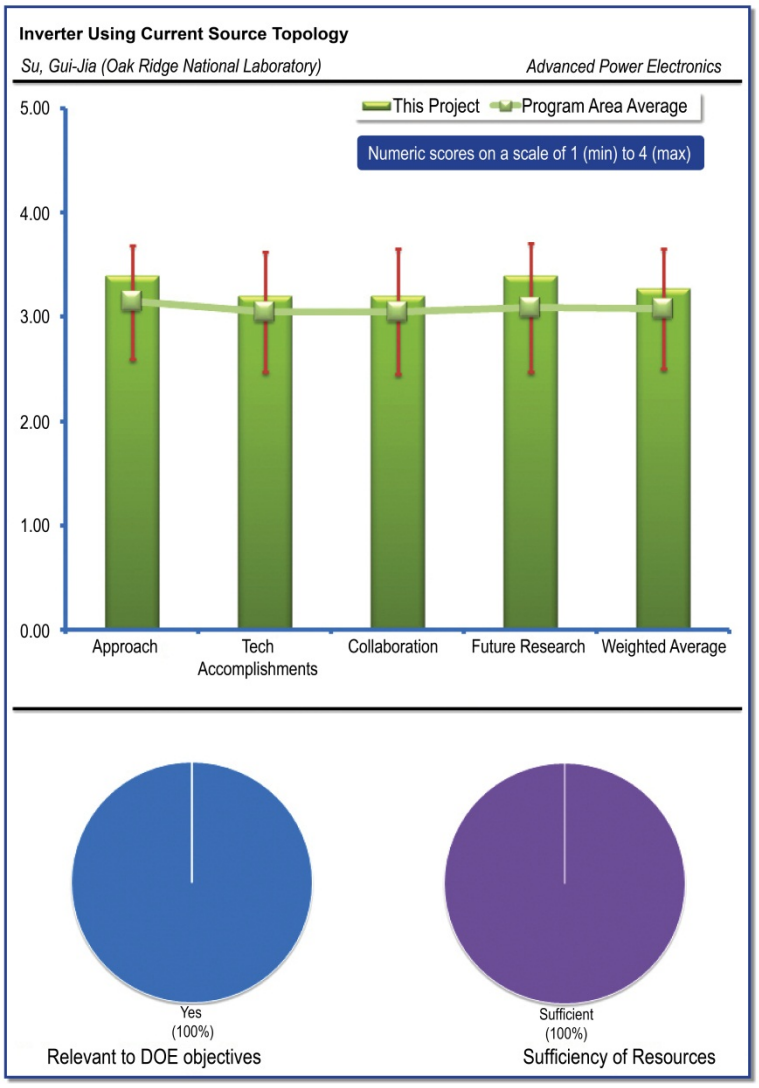
Inverter Using Current Source Topology: Su, Gui-Jia (Oak Ridge National Laboratory) – ape002

Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Most reviewers had a positive response to this question. One person expressed that electrification of vehicles is a vital part of improving energy efficiency in the transportation sector and this inverter has the potential to increase electric drive efficiency. Another reviewer acknowledged that this project will lead to smaller, lighter and lower cost inverters. This work will make it easier for OEMs to place the inverter into the engine compartment. One commenter stated that the potential significant advantages of the current source topology, coupled with Z source inverter paradigm, on dramatic reductions in ripple current and the associated filter passive volume and weight benefit will enhance efficiency, power density, and thus cost. The reviewer added that these benefits will improve the probability of rapid deployment of vehicles with dramatically reduced fuel requirements. The final reviewer remarked that the barriers were explained, but the presenter does not explicitly discuss petroleum displacement.



Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Responses to this question in general were positive. One person simply stated that the approach focuses on reducing the bulk capacitor size and on reducing the motor insulation requirement. Another reviewer applauded that the PI has put together an excellent team that includes Powerex for the reverse blocking (RB) IGBTs and MSU for topology work. The reviewer thought that the new topology for Trans qZCSI has good potential because it has improved boost ratio of 3:1. This reviewer added that this approach could also be used as an on-board charger. The reviewer concluded by stating that the big issues are the new reverse blocking insulated gate bipolar transistors (RBIGBT) which are not readily available and understanding the control on the new current source quasi Z Source topology. Another person commented that the presentation showed a well-balanced approach to the verification and validation of the Z-source current source inverter (ZCSI) for multi-functional application in HEV and PEV applications. They added that the project has an appropriate level of M&S effort to show the benefit to inverter performance and a good experimental validation plan. The reviewer added that they would have liked to have seen some detail on the packaging aspects of the proposed subsystem, including steady state and dynamic thermal analysis. Another commenter observed that combining inverter with boost technology is a sound approach and when combined with advances in the semiconductor arena should lead to an efficient unit with fewer components and thus lower cost. The final reviewer was critical, stating that the researchers show the size of the Camry silicon, but there is no mention of the equivalent RB-insulated-gate bipolar transistor (IGBT) silicon size. They added that the size of the silicon and the added feature

of reverse blocking come at some cost and asked whether this cost can be quantified. The reviewer concluded by acknowledging that otherwise the predicted results look very encouraging.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

Comments to this question were generally positive, but with added suggestions of work to be included in the scope. One person remarked that the project appears to be on track with scheduled milestones completed. M&S results seem to bear out the potential for dramatic ripple current reductions. Another person expressed that the progress to date on the basic technology is very good, but added that they need to see more information on the reverse blocking IGBTs and their commercial viability. The reviewer concluded by stating that the potential for gallium nitride (GaN) is very good as this is a natural feature of the devices. One commenter noted that the simulated results are encouraging, but asked whether some quantification on the Si cost differences may be quantifiable, i.e., what is the difference in cost between a conventional power module rated at 600V / 400A vs. the Fuji 600V / 400A RB - power module. They felt that this quantification would help to validate some of the researchers' cost assumptions. The final reviewer affirmed that this project has demonstrated that all the DOE goals can be met. They noted that the researchers have made outstanding progress and that it will be even better if the inductor can be reduced. They added that the technology shows promise for even more reduction in mass and cost if GaN can be used to increase the switching frequency and shrink the inductor size. The reviewer thought that we may be trading a large capacitor for a large inductor since this is inductor fed. They concluded by that that the good part is the QZCSI which has only six switches and can buck boost.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

Responses to this question were generally positive. One person acknowledged that the team has MSU and Powerex involved, which are both excellent partners. One commenter stated that there is excellent collaboration with university and semiconductor manufacturer that uses the strengths of each to advance the design. Another reviewer noted that the researchers have assembled appropriate university and module manufacturer partners. This person pointed out that the project could benefit from closer involvement of vehicle manufacturers and component producers (passives, active and switching devices). The final reviewer asked whether Powerex will be making a power module with RB-IGBTs, and asked what their role in the project is if not.

Question 5: Has the project 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?

Comments were generally positive, with several reviewers adding suggestions for additional efforts that should be included in the project to improve the project. One person thought that there is great potential for future work on this project to make more improvements, including faster switches using bandgap devices and reducing the inductors. Another reviewer noted that empirical validation of the theoretical and modeling predictions are necessary and sufficient to verify performance predictions. This person added that the researchers could have included a more detailed CSI inverter system test plan, which hopefully includes thermal and dynamic testing over the range of operation space, including re-generation and charging functions. One person applauded the very interesting approach that is focused on validating simulations. This person mentioned that they would like to see some information on the control strategy in the DSP included in the work plan. The final reviewer stated that they would like to see advanced plans based on test performance representative of an actual drive profile. They concluded by stating that the researchers need to show that the potential for increased efficiency with this architecture is possible without sacrificing transient performance.

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

No reviewer provided a comment to this question.

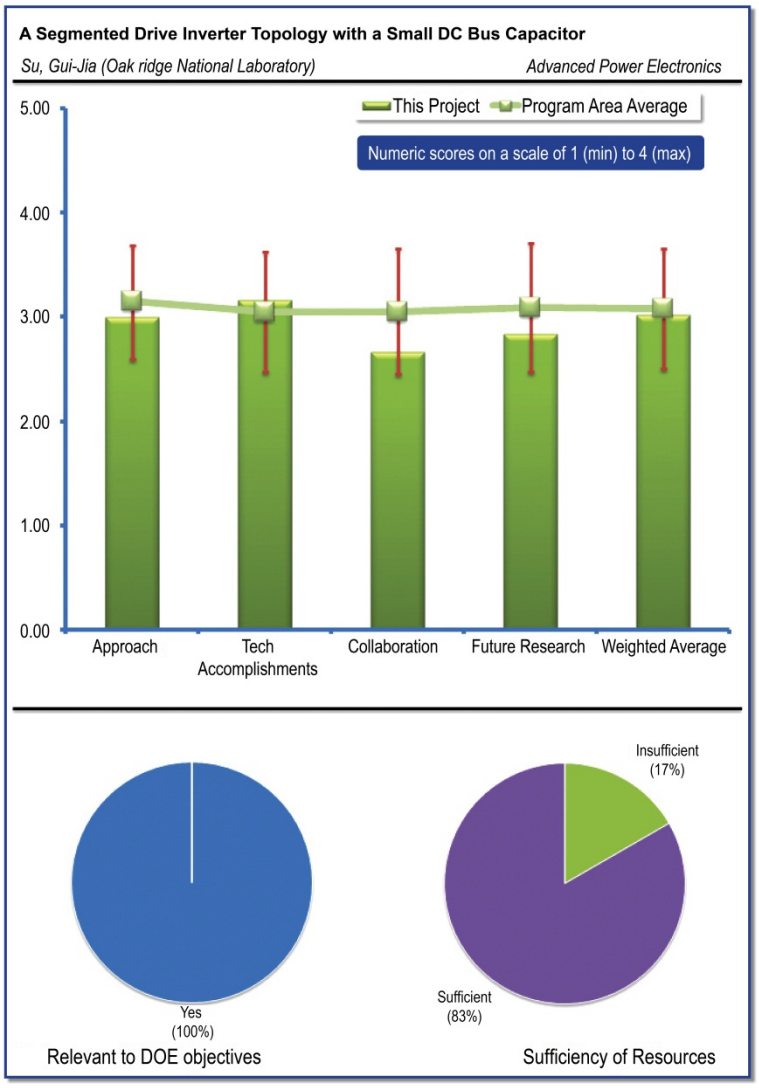
A Segmented Drive Inverter Topology with a Small DC Bus Capacitor: Su, Gui-Jia (Oak Ridge National Laboratory) – ape004

Reviewer Sample Size

This project had a total of six reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Comments to this question were generally positive. One person stated that the project supports goal of increasing power density and reducing cost of electric drive systems. Another person pointed out that traction drive inverters are fundamental to the realization of fossil fuel reduction through the deployment of hybrid and electric vehicle technologies. This reviewer added that this project has merit from a loss reduction standpoint and volumetric and mass power density improvements. One reviewer commented that improved inverter size and weight are important factors in making HEV and PHEV commercially attractive. They added that this project attacks one of the major contributors to both size and weight. Another person noted that inverter size and cost have significant impact on the adoption of electrified vehicles and that ripple current affects EMI and battery performance. The final reviewer commented that the project's support for DOE's petroleum displacement objective was implied but not explicitly stated.



Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Responses to this question were mixed, with several reviewers providing suggestions for improving the project work plan. One person commented that the technology is innovative and addresses key components (high impact) within the inverter. They suggested that quantifying the topology tradeoffs (identifying what is added, not just what is subtracted) would be useful for full disclosure. Another reviewer agreed that the project is highly innovative in its plan to integrate the TDI with the PM machine. The reviewer cautioned that this is however highly risky in terms of the thermal environment the inverter is likely to experience when integrated into the motor case. The packaging and thermal management will be key to successfully achieving this objective. This reviewer concluded by suggesting that establishing a closer partnership with motor manufacturers would be prudent. One person pointed out that since the material is under patent review it is not clear what the approach is, however, simulation results show a reduction in bulk capacitor size and cost. Another person had similar comments stating that the project review is hampered because the presenter did not explain what the approach actually is, so it was not possible for the reviewer to properly review the topology portion of the presentation. They did note that comments may be made regarding mounting the inverter on the motor. One person expressed that the integration of the electronics and the motor will present some challenges. Vibration, temperature, sealing, and EMC may add additional cost to the package. The reviewer asked whether this additional packaging cost will offset the cost of the eliminated motor cables. They concluded by suggesting that the researchers may want to consider the electronics as a separately packaged electronics package that

mounts to the motor. The final reviewer noted that the approach is reducing the current ripple value, but that an acceptable value was not specified. They added that at some point the cost of reducing the battery limit will exceed the benefit. The reviewer concluded by stating that torque ripple also needs to be specified over the speed range.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

Responses to this question were mixed. One reviewer noted that the test results are promising (with the induction motor) and show that this technology has many advantages (battery, capacitor, and motor ripple). They added that the impact on the Toyota Prius motor will be useful, since it has been thoroughly tested and documented in past work. Another person asserted that the presentation of real-world data is an important milestone in showing technical accomplishments. One person commented that the progress appears to be tracking with the schedule and the accomplishment of relevant milestones. They pointed out that M&S is again leveraged appropriately with the empirical validation plan in place. This person concluded by suggesting that more detail should be place on the power module packaging and heat rejection considerations given the plan to integrate with the motor. One reviewer remarked that since the material is under patent review it is not clear what the approach is; it is difficult to evaluate progress. The final reviewer noted that the results show that the approach does limit current and torque ripples. They pointed out that the researchers need clear limits for these to determine when the project has met its goals. The reviewer also asked what the difference in the inductance of the Cap/Bus bar set up between the baseline and the segmented drives shown in the presentation is, asking whether this could this have an effect on the measured values.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

Reactions to this question were mixed. One person simply stated that the collaboration level is acceptable. Another person commented that the collaboration with industry has been proactive and useful to the project. Others felt that the researchers need to go further. One reviewer commented that a closer partnership with motor manufacturer(s) and module packaging expertise would have been prudent given the thermal concerns voiced in earlier question responses. The final reviewer commented that the researchers need to find a motor supplier to integrate the electronics being developed. They cautioned that this is a gap, but is a large part of the cost reduction claims on integrating the motor with the electronics.

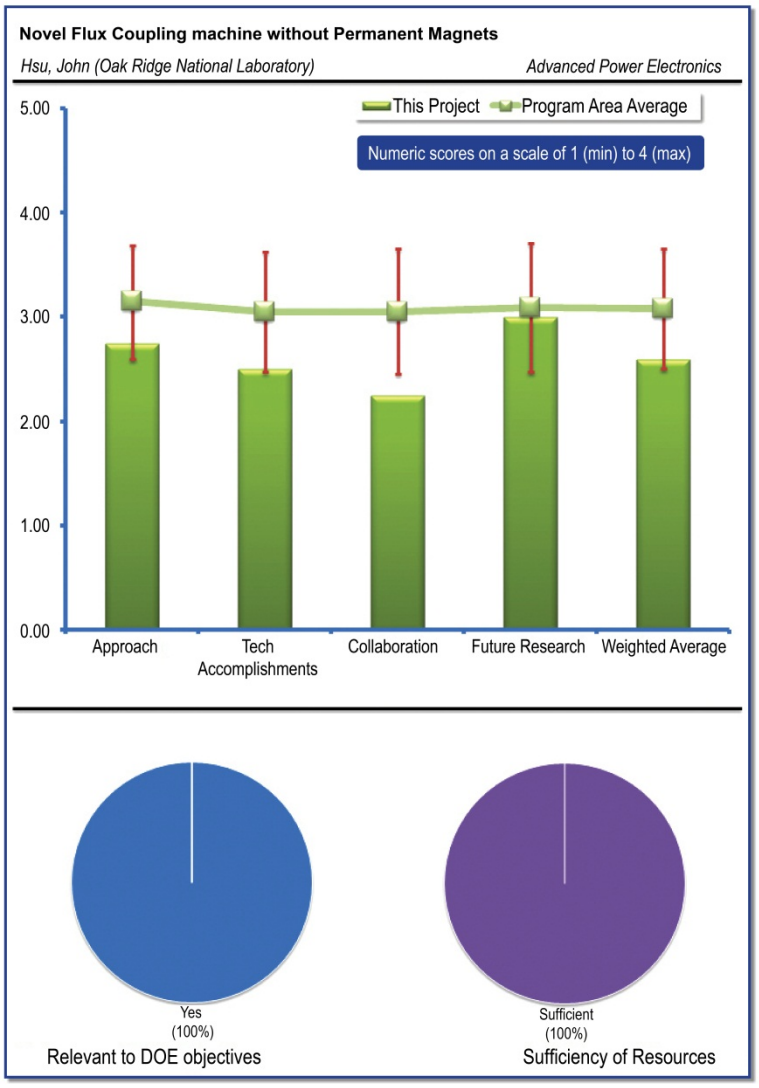
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

Reviewers provided a range of suggestions for improving the scope of the future work. One person stated that the researchers need limits to be sharply focused, and that once they are established the project will be well on the way to success. One reviewer cautioned that adding the physical motor/inverter integration activity should not distract from the main goals of the program; this is a risk. Another reviewer emphasized that experimental validation is fundamental and a key aspect of the next two years effort. They added that the research plan appears to be adequate, provided thermal reliability considerations are prominent. Another person commented that mechanical vibration can be a major stumbling block. This reviewer suggested that consideration should be given to defining the expected environment and modeling the expected implementation to show that the devices will be reliable. Another commenter suggested that the researchers need to include a motor supplier to help with the packaging of the electronics. This reviewer noted that it appears the researchers understand the packaging issues, but still felt that a partner was needed. They concluded by remarking that as to the circuit design, more details of what you are doing need to be presented. The final person commented that quantifying the advantages and disadvantages should be thorough in the context of a separate inverter. This reviewer noted that it is important to measure and present the efficiency differences (motor and controller as a system), since the reduced motor ripple should increase efficiency with the new technology. They added that the researchers should also attempt to quantify the effect on the battery, since reduced DC ripple should increase the available energy in the battery. Between propulsion system efficiency and battery efficiency gains, they felt that this may be a real selling point for the topology.

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

No reviewer provided a comment to this question.

Novel Flux Coupling Machine without Permanent Magnets: Hsu, John (Oak Ridge National Laboratory) – ape005



Reviewer Sample Size

This project had a total of four reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Responses to this question were all positive. One person simply stated that this project possibly eliminates rare-earth magnets in electric motors. Another reviewer commented that the presented motor technology is novel and addresses the current supply/cost issue with rare-earth magnets by eliminating them from this motor. The final reviewer had detailed comments, noting that rare-earth permanent magnets are a major cost factor in PM machines. The new machine design eliminates the magnet materials; therefore, this project has the potential of reducing the cost of electric machines and accelerating the implementation of electric powertrains in vehicles which supports the DOE objectives of petroleum displacement.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

The first reviewer commented that the approach is generally good, although more FEA simulations should have been conducted prior or in parallel to the manufacturing of a prototype machine. This reviewer felt that it is unclear if 3D FEA simulations have been conducted in order to get accurate loss predictions. Moreover, the researchers provide little indication in how far the controls development has been completed especially regarding the control of the field winding. One person commented that it was a good decision that the novel winding technique was not included in the design and manufacturing of the prototype machines as this would have distracted the researchers from their main goal with this design, which is to eliminate permanent magnets. The other reviewer to comment cautioned that the construction of a novel motor like this is complex, so the reviewer would prefer to see the prototype as a two-step process where Step One would prove out the concept and Step Two would offer more optimization to address DOE targets.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

Both commenting reviewers expressed concerns in this area. One reviewer commented that challenges with the prototype construction have prevented test data from being available this year. The reviewer fears that additional fabrication challenges may prevent prototype testing, and again, wishes that the proof-of-concept unit was less ambitious (as described in an earlier comment). The second reviewer felt that it is obvious that the main focus of the work since the last review was on the mechanical design and manufacturing of the prototype machine. The presented simulation results, geometry comparison and cost numbers are basically unchanged compared to the review from a year ago. This is somewhat understandable as the manufacturing of the novel machine

concept presents a major challenge. Nevertheless, the reviewer felt that it would have been good if additional simulation results would have been available, e.g., efficiency predictions. The reviewer pointed out that claims regarding cost reduction are still unproven as it seems that only material costs have been considered but not the manufacturing costs. The reviewer concluded by commenting the fact that the weight of the machine is significantly increased compared to a state-of-the-art interior permanent magnet (IPM) machine is a big disadvantage.

QUESTION 4: WHAT IS YOUR ASSESSMENT OF THE LEVEL OF COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS?

The first reviewer observed that it seems as if there is no collaboration with outside partners besides some support in manufacturing the prototype machine. The reviewer thought that it would be beneficial if a supplier or OEM with manufacturing expertise support the project in order to ensure the manufacturability of the new machine concept in production and improve the cost estimation. The other reviewer noted that some collaboration activities have occurred (e.g., design reviews), but more collaboration with manufacturing would be useful, even at this stage of development.

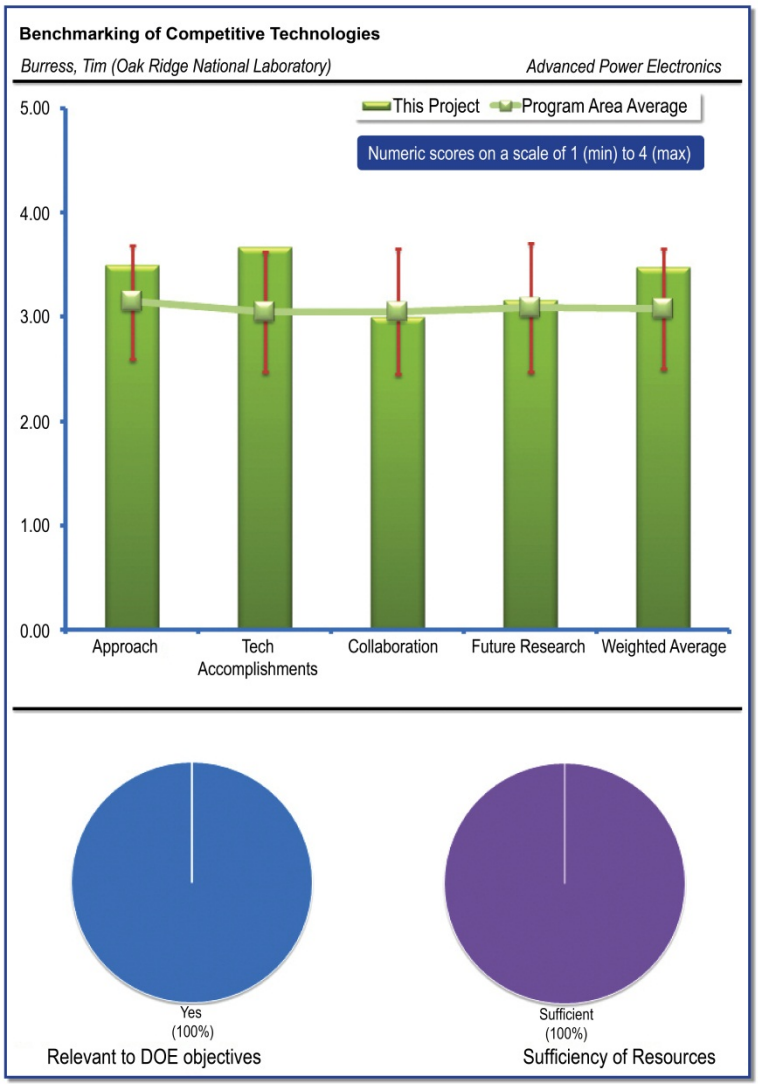
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

The first person said that, assuming that testing occurs in the near future, these will be useful data. If successful, this will be an interesting motor to study manufacturability issues. The other reviewer to comment remarked that the researchers claimed that the project is 80% complete although the prototype machine is not available yet. Therefore, the testing of the prototype machine has not started yet and a lot of tasks have to be completed within just a few months in order to prove the feasibility of the new machine concept.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

No reviewer provided a comment to this question.

Benchmarking of Competitive Technologies: Burress, Tim (Oak Ridge National Laboratory) – ape006



Reviewer Sample Size

This project had a total of six reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Responses to this question were all positive. One person simply stated that the project provides a good understanding of current state-of-the-art in vehicles. Another reviewer noted that this project defines a real-world baseline for current components. (If we are asking for improvement, we must know the starting point.) Another person commented that it is important to understand the best technologies available on the market. This effort will provide a realistic benchmark for the future DOE requirements and also is needed to provide direction for new technologies. Another reviewer commented that the benchmarking of electric powertrains in production vehicles is of very high interest for the domestic automotive industry. The thorough understanding of the design and performance of the technology of competitors helps the domestic automotive industry to improve and accelerate their own development process for electric powertrains which supports the objective of petroleum displacement. The final reviewer noted that the project reflects a key approach to aid in the accelerated deployment of fossil fuel displacing vehicular technology. A systems engineering approach to evaluation and comparison of leading electrical power system technologies is an outstanding approach to achieve this objective. The reviewer concluded by stating that the characterization of selected subsystems is thorough and sufficient to provide the desired performance characteristics of critical electrical and thermal equipment.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

One reviewer simply commented that detailed teardown is the only way to understand what is going on in drivetrain technology. Another person applauded that the step-by-step approach in which the powertrain teardowns were conducted is outstanding. A lot of important information was gained with regard to the design and the performance of the electric powertrain subsystems motor and power electronics. The reviewer felt that the approach could be even further improved if an evaluation in the vehicle could be added in order to investigate the implemented control strategies. One person had detailed comments, stating that the project has focused the work plan and tasks on the critical subsystems that will most directly and significantly impacts DOE vehicular objectives. They described that traction drive inverters, motor, transaxle components, power electronics heat transfer equipment, and boost converter comparisons between relevant manufacturer models will provide tremendous benefit to the technology development effort of DOE in this area. The reviewer concluded by observing that experimental data collection and performance boundary conditions were well defined and laid-out, which are also well integrated with other DOE funded projects aimed at improving the cost, performance, and

reliability of critical subsystems. The final reviewer stated that the approach to evaluating motors could be improved by clearly stating test methods and control algorithms, ensuring repeatability between components.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

All reviewer comments were positive. One person simply stated that the teardowns are well done with a plan. Another reviewer expressed that the comparison photos were impressive, adding that they hope that the more detailed report will be made available to the public. The reviewer believes that there is a lot more details than those presented. This reviewer concluded by congratulating the researchers on the good work determining the efficiency maps. One reviewer expressed that the summary of the findings about the Toyota and Lexus hybrid systems are very good. They added that it would be beneficial if the test conditions and control strategy are described in more detail because this would provide an even better understanding of the test results. The reviewer noted that work on the Hyundai system has been started this year and it will be very interesting to see the results of the complete teardown. The last reviewer noted that very good progress made in advancing the evaluation of newer model years' technology and comparing to benchmark standards of previous models. They pointed out that the efficiency mapping and the discovery of the PCU thermal pathway advances in the 2010 Prius should be very beneficial. They concluded by adding that it appears to be a very fruitful activity, which is accomplishing the goals and objectives of the project in an effective fashion.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

Comments were generally positive. One person felt that there was very good cooperation with other groups. Another person observed that there was an appropriate mix of technical expertise from National Laboratory centers of excellence in relevant areas. The final reviewer to comment acknowledged that the collaboration between a number of National Labs seems to work well. The reviewer felt that it would be beneficial if subject matter experts for every subcomponent would get more involved in order to achieve an even higher depth of understanding.

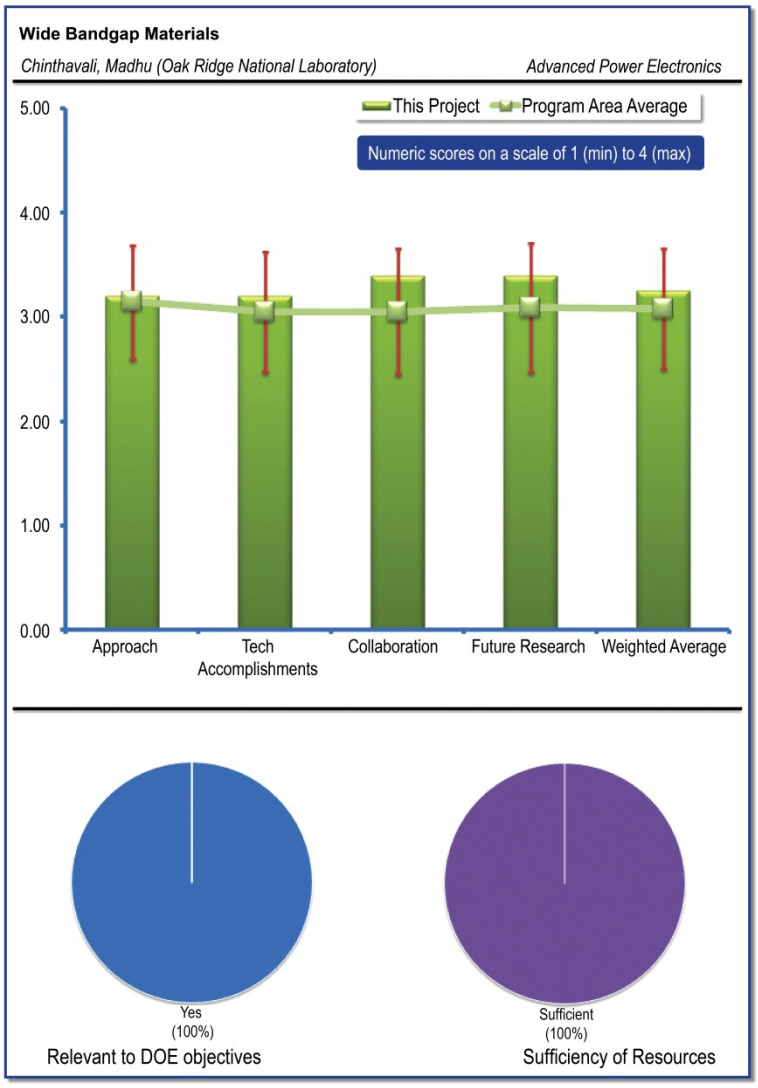
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer commented that no future plans were presented. Others explained that the project effort is on-going. One person commented that this is an on-going program and properly proposes to continue looking at production items of interest. Another commenter also explained that the project is an ongoing effort and additional teardowns of electric powertrains will hopefully follow the current task which is focused on the Hyundai Sonata Hybrid. The reviewer felt that it would be outstanding if technology from foreign markets could be investigated too, e.g., the upcoming hybrid and electric systems of Renault and Peugeot (rear-axle hybrid). The final reviewer commented that the proposed completion of Hyundai benchmarking efforts during the coming year will provide an excellent complement to the vehicles already completed or ongoing.

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

No reviewer provided a comment to this question.

Wide Bandgap Materials: Chinthavali, Madhu (Oak Ridge National Laboratory) – ape007



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

One reviewer emphasized that improved inverters and converters are key factors in HEV and PHEV technology. Power electronic components are at the heart of those components; make those more efficient and fully understood, and the entire system benefits. Another person pointed out that wide bandgap semiconductors are an emerging advanced device technology that can lead to reduction of overall size and weight of inverter and enable higher temperature operation. Device benchmarking is important because many experimental devices are being introduced from multiple labs and vendors. Another reviewer stated that wide bandgap device would allow higher temperature operation to save the power electronics system cost. Another agreed, adding that wide bandgap devices offer the potential for significant increases in the efficiency of switching devices. To take advantage of this, a package will be required that allows the user to take full advantage of the device's characteristics and this project is exploring this area. The final reviewer had detailed comments, describing that the baseline characterization, SPICE model development, and performance qualification of the silicon carbide power switching and rectifying devices being conducted under this project are fundamental to the integration of these performance enhancing technologies into highly efficient drive and conversion components. The potential improvements to vehicle efficiency and reliability that these power device technologies will afford can further reduce fossil fuel consumption beyond the silicon-baseline hybrid and PEV vehicular entitlement. As these are newly emerging technologies, the quantitative characterization of real performance potential is crucial to understanding the overall system impact and cost benefit analysis required for deployment.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Responses to this question were generally positive. The first reviewer commented that the project has a number of test and modeling tasks that are important including static and dynamic testing, behavioral spice models, and loss model calculations. The reviewer explained that the test and modeling procedures are being performed for a wide range of wide bandgap device types: JBS, BJT, MOSFET, JFET (1,200 V / 100 A range). Another person observed that the project reflects an excellent objective analysis of competing and compatible power switch and rectifier technologies potentially suitable for significant performance and reliability improvements in vehicular applications. In addition, the effort highlights the subtle differences between silicon carbide (SiC) and Si power electronic devices, especially in terms of gate control. The reviewer felt that this aspect of the project is very useful for potential suppliers and vehicle manufacturers to understand prior to attempting to integrate the new technologies into products. One commenter felt that the project has an appropriate focus on sharing data that designers will need to implement next generation components.

Another reviewer commented that the use of a model for comparisons is very good as long as the model is realistic and provides reasonable results. The reviewer asked if the model has been checked to determine how realistic it is. They concluded by noting that focusing on the capabilities at ORNL should help as the expertise and equipment is readily available. The final reviewer suggested the researchers add the system level (inverter or DC-DC) testing data to demonstrate the benefit in additional to simulation.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

Responses to this question were mixed with some reviewers providing suggestions for improving the work plan. One person simply stated that the progress to date is very good as is access to the data. Another reviewer affirmed that measurable progress has been demonstrated and scheduled milestone objectives achieved. They felt that this appears to be a well-executed task which is generating highly useful and applicable data for vehicle component developers and manufacturers. The web-availability of data generated under this task is a highly attractive aspect of the subject project. They concluded by stating that this will certainly help accelerate the utilization of these performance enhancing technologies by enabling developers to conduct modeling and design trades using SOTA performance parameters. One reviewer remarked that the researchers need to speed up the system-level simulation. Another person acknowledged that leakage tests were done on a parallel combination of IGBT and diode together, but asked why these were not measured separately to evaluate technology. One person stated that the project could be improved by sharing not only component models, but models for inverter, motor, etc. The final reviewer commented that some of the modeling approaches and test procedures are not on par with the state-of-the-art in other labs, for example, the behavioral SPICE model for JFET switching results are shown for dynamic conditions and a time scale where the waveforms do not depend on the device models, only the circuit model. They noted that the turn-on current spike does depend on the devices' behavior but the time scale does not permit evaluation of the model performance. Also, gate voltage and current waveforms are needed to demonstrate accuracy of models.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

Responses to this question were all generally positive. One person pointed out that the project leverages all available device manufacturers and device types for analysis; this could only be accomplished with the intentional cooperation and collaboration of the manufacturers. Another person commented that the coordination to-date has largely involved obtaining samples to test from vendors and research programs. They added that very little collaboration with other test labs with state-of-the-art test and modeling approaches has been demonstrated. Another reviewer emphasized that the evolution to a common package configuration is an important step to improving collaboration. The final person stated that the collaboration is excellent so far. This reviewer added that future work may require involving additional suppliers of wide bandgap devices as well as analysis of package inductance and thermal performance, which the reviewer believes the capability to do this exists. The reviewer concluded by asking how much interaction has been accomplished with industry in general (industrial power module suppliers).

Question 5: Has the project 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?

One reviewer stated that if the project continues as scheduled, the contribution will continue to be significant. Another person noted that progress is based on current status. They cautioned that the ability of these devices to switch at very high rise times will lead to potential issues within the package and for the die due to the inductance of theinterconnects. Another concern is the thermal limitations of the interconnects and device bonding methods - current silicon device performance has been limited in the past due to the limitations of the solder used to attach the devices and the wire bonding process; these need to be addressed in the future plans. Another reviewer pointed out that the project leaders, in response to reviewers comments from AMR 2010, chose not to consider reliability-related metrics in the device assessment. The reviewer cautioned that this diminishes the value of the evaluations given that the characteristics measured by the project are closely tied to possible compromises in material quality and device design that impact reliability. For example, a 1,200 V SiC MOSFET can be made with substantially lower on-resistance with today's technology simply by designing the device to operate at a much higher gate oxide field; however, this substantially diminishes the device life expectancy especially at elevated temperatures. Also, much lower on-resistance devices can readily be made using bipolar type devices but the primary technology barrier for bipolar devices in SiC is the material quality based stacking fault induced forward bias degradation.

The reviewer recommends using a more holistic assessment of the technology readiness and performance rather than just measuring forward conduction and switching waveforms. The final commenter mentioned that some of the future tasks proposed are not relevant considering the current quality of measurement and modeling approach demonstrated by the project; for example, if models use constant inter electrode capacitances then there is no value in characterizing terminal inductances which will have much less impact on dynamic behavior than the nonlinear inter electrode capacitances.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

No reviewer provided a comment to this question.

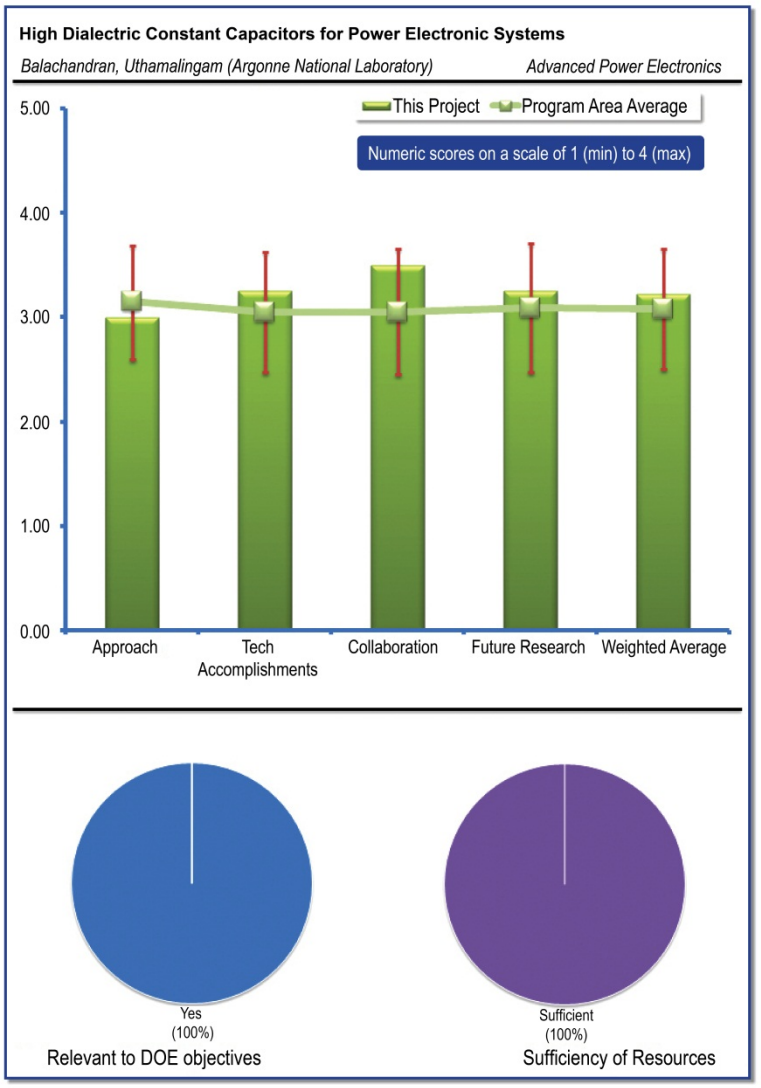
High Dialectric Constant Capacitors for Power Electronic Systems: Balachandran, Uthamalingam (Argonne National Laboratory) – ape008

Reviewer Sample Size

This project had a total of four reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Responses to this question were all positive. One person pointed out that capacitors are one of the major cost drivers for traction inverter systems. Another reviewer commented that these advanced technology capacitors will be needed in greater quantities as their use in hybrid vehicles proliferates. Another reviewer emphasized that more effective inverters and converters are an important part of the PEV and HEV strategy. Capacitors are a major barrier to reducing cost and expanding operating environment. This project has the potential to address both of those concerns. The final person commented that capacitors that meet the needs of the power electronics world, such as high voltage ratings, and the ability to survive high temperatures while providing sufficient capacitance in a small package are very difficult to find. The approach in this project has the potential to solve this issue if the performance goals and costs are met.



Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

One reviewer remarked that this project involves interesting work toward goal, but there is a lot of work to do with a lot of unknowns. The reviewer noted that modeling is difficult for newer materials, so this reviewer hopes the project gets to its objective. The other commenting reviewer stated that focusing on the technical barriers is good, but the researchers need to include robustness to environmental forces (such as moisture and vibration).They added that the researchers also need to be aware of the requirements of the manufacturing world on the packages selected for the devices.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer commented that the project results show that impressive work has been done while exploring many unknowns. This reviewer would like to see more specific plan to achieve higher voltage capability. Another reviewer expressed that the progress to date shows excellent potential and results. They questioned where the target value of 1,000μF came from, because having a clear set of requirements will help keep the research team focused. The final reviewer commented that it would be more impressive to build a stacked capacitor that could be used with voltage, which they acknowledge is probably in the plan. The reviewer offered an aside, stating that comparative data should be shown using charts with the same axis scaling (e.g. Slide 9, capacitance vs. bias field).

QUESTION 4: WHAT IS YOUR ASSESSMENT OF THE LEVEL OF COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS?

Comments to this question were all positive. One person simply stated that the research team appears to be working well together. The other commenter remarked that it appears the researchers are working with all the right folks. They also noted the good support from industry, academia, and national labs. The reviewer concluded by stating that if the researchers cannot get there, it is likely not practically feasible.

QUESTION 5: HAS THE PROJECT 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?

The first reviewer commented that if successful, the researchers will have an excellent capacitor. Another reviewer observed that the research is headed in the right direction. The vision is simple, but technically conquering challenges is not simple. Another reviewer agreed that it is appropriate to focus on building stacked capacitors at 450V range since that is what industry needs now, but they encouraged the team to consider 600V as a working voltage. The final reviewer suggested the researchers consider building a 1,000 μF/450C capacitor in the future plan to evaluate the full performance.

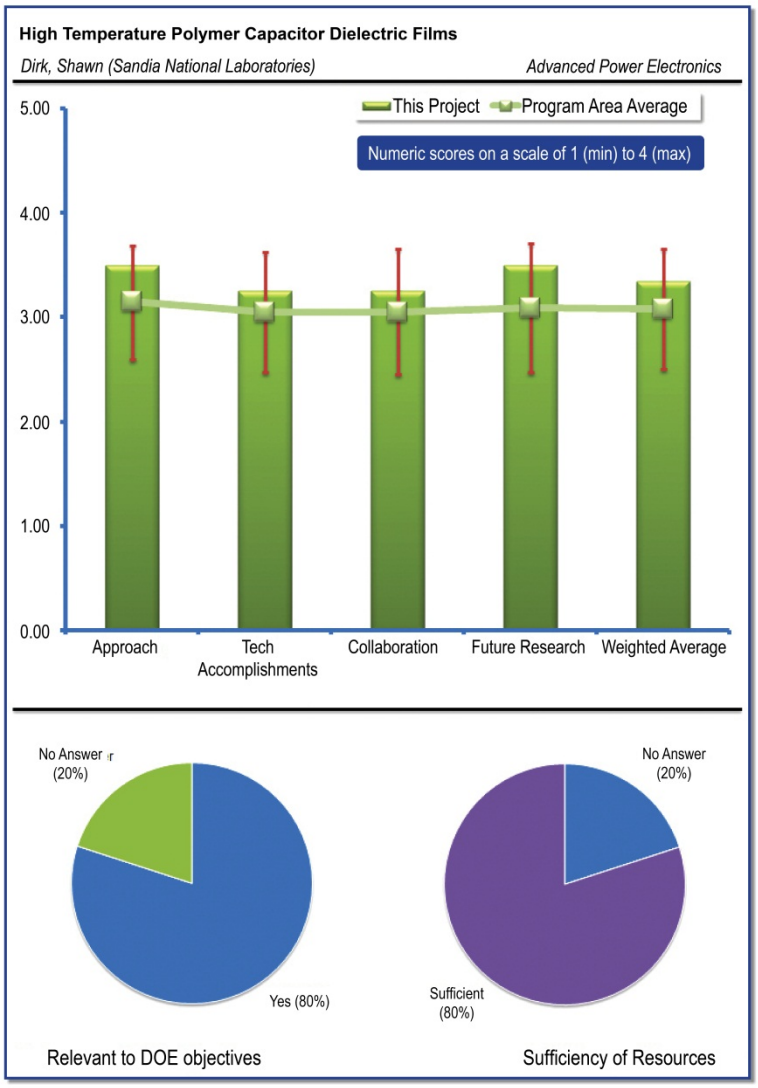
QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

No reviewer provided a comment to this question.

High Temperature Polymer Capacitor Dielectric Films: Dirk, Shawn (Sandia National Laboratories) – ape009

Reviewer Sample Size

This project had a total of 5 reviewers.



Question 1: Does this project support the overall DOE objectives? Why or why not?

Responses to this question were all positive. One person noted that this was a good project as capacitors represent a significant cost and size impact to inverters. Another reviewer agreed, stating that capacitors are one of major contributor to the inverter in size, weight and cost, so this project's objectives to reduce these characteristics lines up with DOE goals. Another reviewer commented that these high-tech capacitors will be needed in much higher quantities in the future to support the proliferation of HEV vehicles. The final reviewer explained that more effective inverters and converters are an important part of the PEV and HEV strategy. This reviewer added that capacitors are a major barrier to reducing cost and size, and are a constraint regarding expanding operating environment, so this project has the potential to address these concerns.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Both responses were positive. The first reviewer commented that the approach is very solid. They point out that exacting and demanding work lay ahead, that the specific tasks and goals are clearly laid out as well as tactics and means to pursue them. This reviewer concludes by stating the strategy to solve problems looks very solid. The other reviewer to comment pointed out that the approach focuses on the issues with today's capacitors. They added that the materials chosen seem to be promising in terms of meeting technical goals.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

Comments were all positive. One person stated that the researchers were very strong here. They added that understanding the nanoparticle filler material use to extend BV is a strong accomplishment; doing so in a cost-effective manner is even better. Another reviewer commented that good work was shown on solving development hurdles (altering materials in a scientific manner rather than just trying stuff). The final reviewer observed that progress is good, but have they investigated the current method of extruding films to see if they can learn from it - especially in the area of lessons learned.

QUESTION 4: WHAT IS YOUR ASSESSMENT OF THE LEVEL OF COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS?

Reactions to this question were generally positive. The first reviewer felt the project has good collaboration with what looks to be all the appropriate folks from industry, academia, and National Labs. The second reviewer commented that the collaboration appears acceptable, but reissued their earlier comment regarding involving industry contacts.

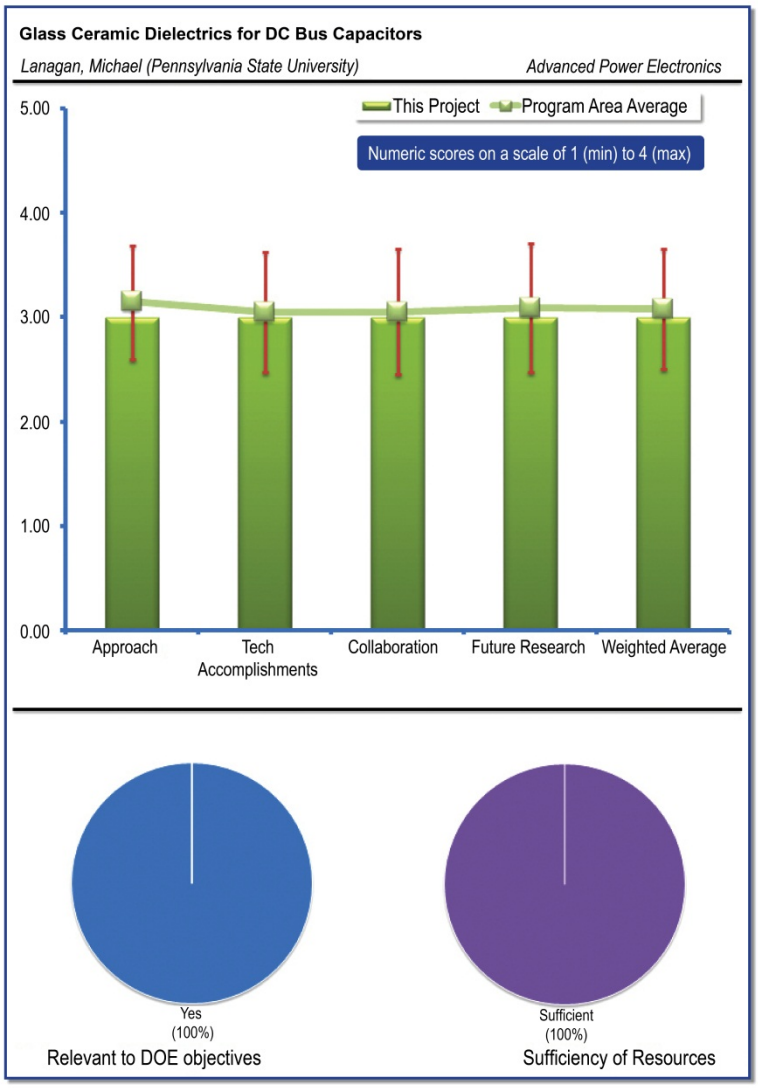
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

One reviewer commented that the future research to advance the extension of BV is good. Another person commented that continuing to use cost-effective materials makes sense to a great degree. They added, however that working toward extrudable material seems very beneficial. Another reviewer stressed that it is important to actually fabricate a stacked capacitor that demonstrates meeting the requirements; this will show it is possible to bridge the gap between a lab demonstration of a small capacitor to a useful device. The final reviewer agreed the progress and plan are correct, but asked what is the ability to redirect the project scope if results indicate a change is required.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

No reviewer provided a comment to this question.

Glass Ceramic Dielectrics for DC Bus Capacitors: Lanagan, Michael (Penn State University) – ape010



Reviewer Sample Size

This project had a total of three reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

One reviewer remarked that capacitors are a significant cost and size impact in inverter design. The other reviewer to comment asserted that more effective inverters and converters are an important part of the PEV and HEV strategy. Capacitors are a major barrier to reducing cost and size, and are a constraint regarding expanding operating environment, so this project has the potential to address these concerns.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

The commenting reviewer remarked that the approach has potential but had concerns relative to how do these capacitors compare to existing film and ceramic caps. This reviewer also wondered what the limitations will be in terms of the environment.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer said that the progress to date is good but that the researchers still have a ways to go to prove technology. The other reviewer expressed that the presentation would be enhanced by a description of the self-healing mechanism, but the reviewer understands that it is in the patent process.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

The only respondent commented on the good collaboration in areas of the investigation, but suggested that the researchers may want to also involve film and ceramic capacitor experts.

Question 5: Has the project 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?

One reviewer said that the plan is great if the data supports the goals. The commenting reviewer suggested that the future work should include fabrication of a large C high V component.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

No reviewer provided a comment to this question.

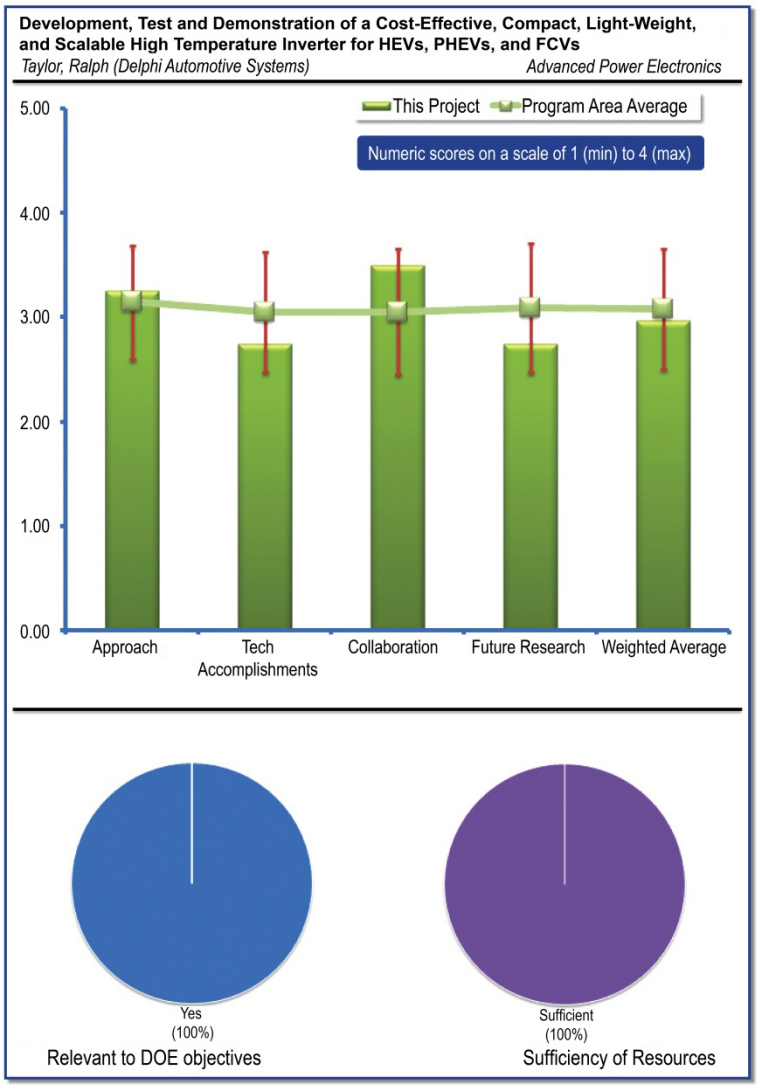
Development, Test and Demonstration of a Cost-Effective, Compact, Light-Weight, and Scalable High Temperature Inverter for HEVs, PHEVs, and FCVs: Taylor, Ralph (Delphi Automotive) – ape012

Reviewer Sample Size

This project had a total of four reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Responses to this question were positive, with one person simply stating that this work is required to support electrification of the vehicle. Another reviewer explained that the project is addressing advanced inverter technologies and integration approaches. The project goals are to reduce size, weight, and cost while increasing performances in key areas such as high temperature operation. The last reviewer commented that a necessary prerequisite for successful deployment is the demonstration, and ultimately production, of reliable, highly efficient, lightweight inverters for vehicle traction drive applications. They added that this program correctly addresses these issues from an integration standpoint, but also includes appropriate subtasks to evaluate potential emerging technologies which may have significant impact on the ability to meet longer range goals and metrics.



Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

One reviewer stated that the project utilizes a concurrent engineering approach for development and integration of multiple advanced inverter technologies. The approach includes development of individual component technologies with both high- and low-risk options as well as technology integration accounting for the interaction of multiple new and existing technologies. The reviewer felt that this is a major strength of this project. Another reviewer had detailed comments, observing a well-organized program structure with a focus on the performance metrics. The reviewer did not feel that the prime is functionally on-board with the longer term technologies, but rather included them for the purposes of saleability. This is an ingrained legacy auto industry mindset that needs to be eliminated in order for true innovation in the industry to occur. This can only begin by performing cost analysis at a systems level, which the reviewer did not see occurring. In addition, the reviewer added that the "innovative" technologies selected for the project subtasks do not reflect the best choices for power device or capacitor technologies. SiC/Si is a long shot technology at best, and the dielectrics considered do not reflect understanding of the very large investment required to scale-up and begin production of a film capacitor technology. GE and Purdue will never go down that path. The power device packaging appears innovative, but there is no analysis or consideration of reliability in a dual sided packaging from both a delta-T or voltage failure standpoint. The reviewer concluded by commenting that they expected more from a primary top tier auto industry supplier. One reviewer noted that the thermal path is being addressed as is thermal capacity of the capacitor. The power switch simulation is dependent upon the accuracy of the losses of the device and package, so the reviewer wondered if this has been done, cautioning that an error here can lead to better model based

performance than the real-world. This reviewer cautioned that the layout of inverter may lead to issues that are not related to technology, i.e., 3-phase leads passing through the middle of the unit may cause issues on the cards around it. The reviewer concluded by asking whether the cables are shielded.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer noted that the multiple technologies being developed are at various readiness levels. Considering those technologies that are likely to be integrated during the term of the project, the project does substantially improve on the state-of-the-art and may meet the DOE goals if optimized. However, a few of the high payoff technologies being considered (such as the SiC-on-Si devices and possibly the Film-on-Foil capacitors) are too far from ready to impact the project under the current term. Another person expressed that the progress is hard to judge since the inverter has not been built and tested. This reviewer liked the approach of using two different caps representing medium- and high-risk. The reviewer was very concerned about the plan to receive parts, build unit, and expect it to work; new technology will require some care and feeding to get operational so presents a schedule risk. The final person criticized that they did not see measurable progress from the previous year, especially from Delphi's tasks. The reviewer asserted that the subtasks are highly unlikely to produce anything tangible during this project. The significantly reduced thermal impedance of the power device packaging will carry with it an associated susceptibility to dynamic thermal events (peak power demand, etc.). With a reduction in heat capacity and the plan to operate the IGBTs closer to their thermal limit a careful non-steady state thermal study is necessary. Similarly, dual-sided cooled power device packaging has historically had voltage breakdown/arcing type failure modes which Delphi has not addressed from a reliability standpoint.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

Responses to this question were all positive. One person noted that the project includes a well-balanced group of partners with a diverse range of expertise relevant to the subject program. Another reviewer agreed that there is good collaboration in terms of advanced devices and capacitors. The final reviewer commented that the coordination between multiple technology development and analysis tasks within the project and with other Vehicle Technology Program efforts is outstanding; this is a major strength of this project.

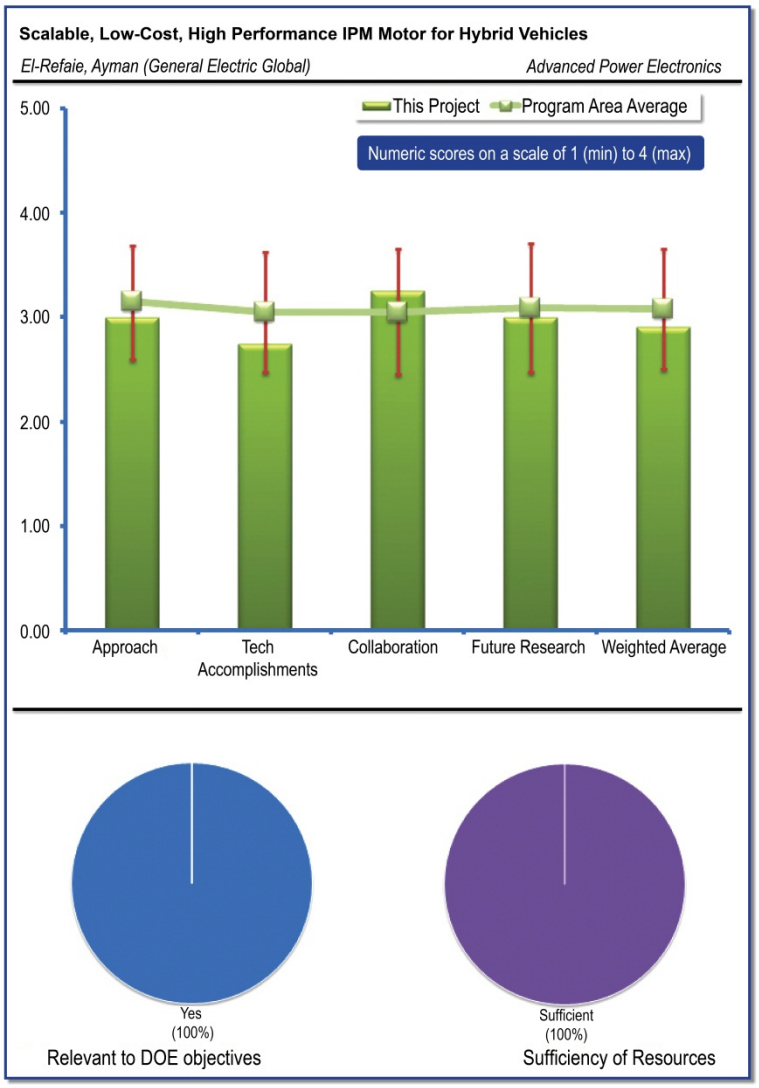
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One reviewer simply stated that the researcher has an acceptable plan in place to hopefully build and test a functional inverter. Another reviewer commented that the remainder of the project is well-planned and the technology integration approach is credible. However, the reviewer cautioned that there seems to be a compressed schedule for device and inverter testing for the few technologies that are not ready. They felt that the overall project may be more successful if there were more aggressive down-selection of technologies being considered for inverter integration; the project might consider continuing the research and development on the technologies that are not ready but focusing the inverter integration work on those technologies that will likely be ready to meet the inverter integration and testing schedule. The last reviewer thought that it is unrealistic to believe that the research team is going to get parts in-house, fabricate and inverter, assemble it, bench test it, and run it on a dynamometer in 6 weeks. They added that the unit probably will not have the correct cap either.

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

No reviewer provided a comment to this question.

Scalable, Low-Cost, High Performance IPM Motor for Hybrid Vehicles: El-Refaie, Ayman (General Electric Global) – ape013



Reviewer Sample Size

This project had a total of four reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Responses to this question were positive. One person noted that the goal of the researchers is to develop an IPM machine with high-efficiency and low cost. Another reviewer expressed that this is very important work to improve the performance and mass of the electric motor. Another reviewer remarked that improved electric machines support vehicle electrification. The final reviewer emphasized that such electric machines are necessary for the broad implementation of electric drive systems in vehicles and thus support the DOE objective of petroleum displacement.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

One reviewer commented that the technical barriers of a high-speed, high-efficiency motor seem to be identified by the researchers with suggested improvements in the rotor design. Unfortunately, some of the measures which have been applied in the new rotor design are not disclosed in detail so it is difficult to evaluate these. With their approach the researchers try to meet the very challenging high-speed efficiency requirements, but this might lead to higher manufacturing cost of the machine, e.g., due to higher PM material content. Another reviewer agreed, pointing out that GE has taken a broad approach to innovative motor design. The reviewer also added that it is difficult to judge the specifics since they were not presented, however the design approach is excellent. Another commenter stated that the embedded technology is not described in detail, but it appears that the approach focuses on incremental improvements (higher resistivity magnets) and not high impact technologies that would be typical of an advanced R&D program. The reviewer explained that the original innovations (e.g., high resistivity and soft magnetics) were eliminated from the program, perhaps with good reasons, but also in order to reduce the value of the program. The final person simply asked whether the new design benefits the manufacturing cost.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

Reviewers provided a range of technical questions and insights. One reviewer warned that the segmented stator with concentrated winding might lead to higher harmonics causing losses in the rotor. This is addressed with the development of permanent magnets with higher resistivity and additional measures in the rotor. The reviewer suggested that it would be interesting to see a detailed cost tradeoff between the new magnet material with insulating layers and the conventional approach of segmenting the magnets axially. Another reviewer expressed concern that that the second proof of principle machine shows little improvement over the first machine

and it offers only modest progress. Parameters of the second machine should have resulted in more efficiency gains at high speed. They acknowledge that testing of the third machine may show improvement. Descriptions of early results were communicated to be better, but still fall short of targets. The reviewer, however, acknowledged that the DOE targets are aggressive and are difficult to achieve. Another reviewer noted that three generations of prototype machine have been built and the lessons learned from the previous prototypes have been applied to the design of the next prototype. The reviewer felt that the researchers have a clear path of addressing issues, always with the focus on meeting the challenging DOE requirements for a high-speed electric machine. The final reviewer described that the results to date show that an improved machine can be designed but the cost will be much higher due to unique processes and parts. The research team has made great progress in most of the important machine parameters as shown in the presentation, however there were some metrics that were not met, such as back EMF and cost. The reviewer wished that they could see more details of the motor design, but understands the proprietary nature of the work. The reviewer concluded by hoping that this work will lead to some new advancements in motor technology.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

Comments to this question were primarily positive. One commenter commented that the collaboration with universities and key component suppliers are appropriate. Another stated that GE has many good partners including internal divisions and outside consultants. The final reviewer to comment agreed that the collaboration between industry partners and universities is well coordinated. The reviewer felt that that the role of the supplier Electron Energy Corp. in the PM development should be described in more detail as it seems that this partner was not part of the project from the start.

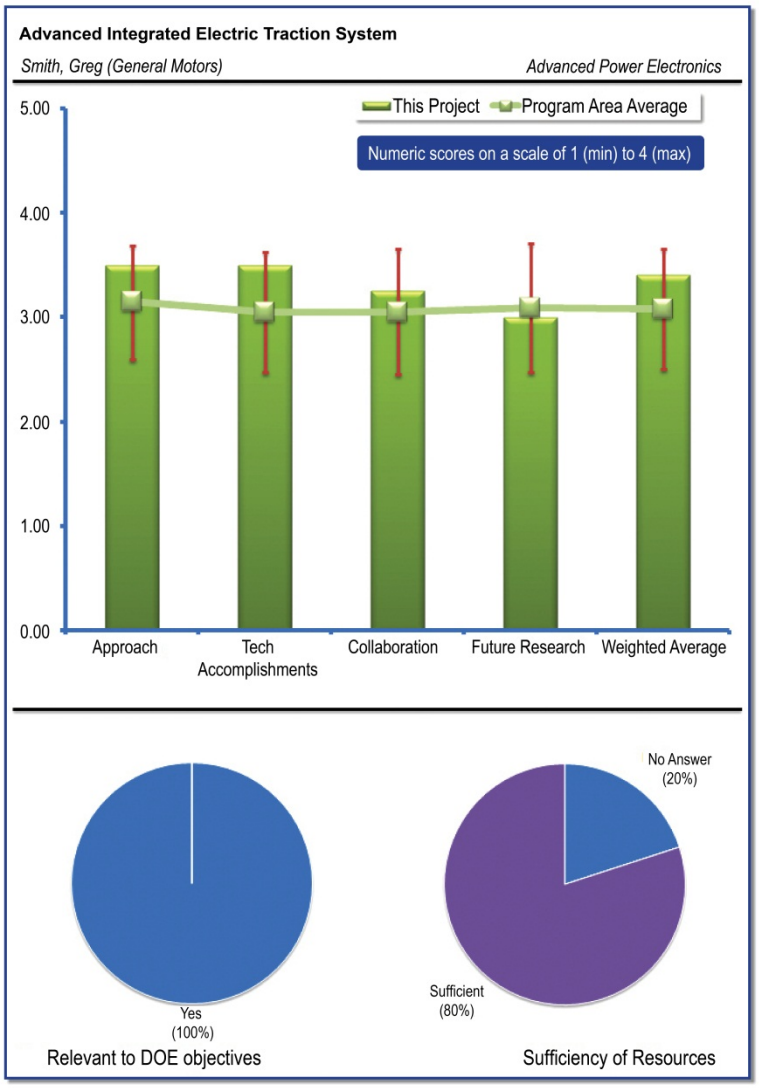
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One person simply stated that the work is almost done so there is not much left for future work. Another commenter had a similar comment, pointing out that the researchers plan to complete the testing of the final 55 kW prototype machine soon; this is necessary to prove the claimed results. Another reviewer described that the third 55 kW prototype is based upon results of the first two prototypes. The 120 kW system is appropriate to address the increasing power demands of vehicle manufacturers and the reviewer hoped that the program budget and timing allows for the build of this higher power version. Another person stated that the future work is very interesting and will include the evaluation of the scaled prototype machine with 120 kW because this power level seems to be more appropriate for the vehicle applications into which the new high speed machine design would fit best (BEV, FCEV). The final reviewer thought that it would be interesting to see the results of a tradeoff for the cost between a higher speed/lower torque and a lower speed/higher torque machine design with the latter being a better fit for HEV applications in which the electric machines are integrated into the transmission.

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

No reviewer provided a comment to this question.

Advanced Integrated Electric Traction System: Smith, Greg (General Motors) – ape014



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Two reviewers felt the project supports DOE's goals. One commenter simply stated that the project supports the goals. The other reviewer observed that the integrated systems development from an experience vehicle manufacturer supports vehicle electrification. Another reviewer had a related comment, but did not directly address whether the project supports the objectives, stating that this is a system level project by an OEM with the possibility of commercialization. The final reviewer commented that the project investigates advanced technologies, system integration and interfacing and manufacturing issues for Advanced Integrated Electric Traction Systems (ETS). The reviewer pointed out that the goals are to reduce cost, size, weight and increase efficiency, reliability, and manufacturability, and enable 105°C coolant, but did not mention whether these support DOE's petroleum reduction goal.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Comments were positive to this question. One commenter explained that the project utilizes results of Phase 1 demonstration project and applies detailed design requirements and lessons learned from demonstration builds and testing to ensure compatibility with existing vehicles, ensure manufacturability, and meet advanced requirements for the ETS. Another reviewer observed that GM took a systems approach to the design and used practical manufacturing processes. The reviewer felt that the design that resulted is innovative but accessible. The final reviewer commented that the development approach was thorough and many tradeoffs were studied, including forward-looking manufacturing issues. They added that novel concepts were attempted as part of the plan.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One person explained that the project is 97% complete and has completed hardware and witness testing and have met 2010 requirements and some of 2015 requirements. The reviewer added that the ETS works over full range of automotive conditions including extreme cold and hot etc., not just bench demonstration. The project has consideration of the impact of advanced technology on other system components such as interfaces, variability of prototype components, etc., and has identified and addressed key concerns in this area. Accomplishments and lessons learned include: 1) soldering to heavy Cu board, pin alignment, thick board aspect

ratio requires larger diameter vias, 2) identified gate drive grounding issues, and 3) identified poor louver contacting issues. Another reviewer commented that the lessons learned were shared, good and bad, which is useful to others and is not always released to the public. The reviewer added that many of the negatives regarding the 5-phase machine were shared (coil inductance and manufacturing challenges) and it will be useful to see the advantages relative to inverter kVA and bulk capacitance reduction. The reviewer hoped that if the conclusion is that 5-phase machines have more drawbacks than advantages, that this is noted in the report. Another commenter thought that the fact that the researchers were able to meet all the DOE requirements, except cost was excellent. Cost is always the most difficult parameter because it usually means reducing the amount of basic commodities such as steel, copper, etc. which is very difficult. The reviewer concluded by applauding that the performance of this system looks great and the packaging was executed well. Two reviewers had critical comments. One stated that gate drive highlighted as too many parts, and layout and traces encroach on heavy copper layers. The final reviewer questioned what the actual achievement on the cost target was.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

Responses to this question were positive. One person noted that suppliers and laboratories were engaged in the program. Another commenter remarked that the team for this project had many diverse companies and institutions. The final reviewer acknowledged that the project has numerous partners with Tier 1,2, and 3 suppliers in motor, inverter, and charger, as well as national labs. The reviewer thought that this coordination has provided benefit to the project and has provided input into other projects within Vehicle Technologies Program.

Question 5: Has the project 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?

One reviewer noted that the work is basically done except for the report. Another person had similar comments and stated that the program is being completed and that the report with its conclusions will be interesting and the lessons learned will be helpful. Another reviewer explained that vibe testing will be among last things done, to preserve the units rather than test to destruction. One commenter noted however that the project has identified priorities for future work and that power density and specific power have become less of an issue whereas efficiency is more important and cost is the priority. One reviewer pointed out that the power module, capacitor, and rare earth magnets are the priorities for cost concerns. The final reviewer suggested that in order to reduce cost, the ETS development needs to consider full system integration not just individual components.

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

No reviewer provided a comment to this question.

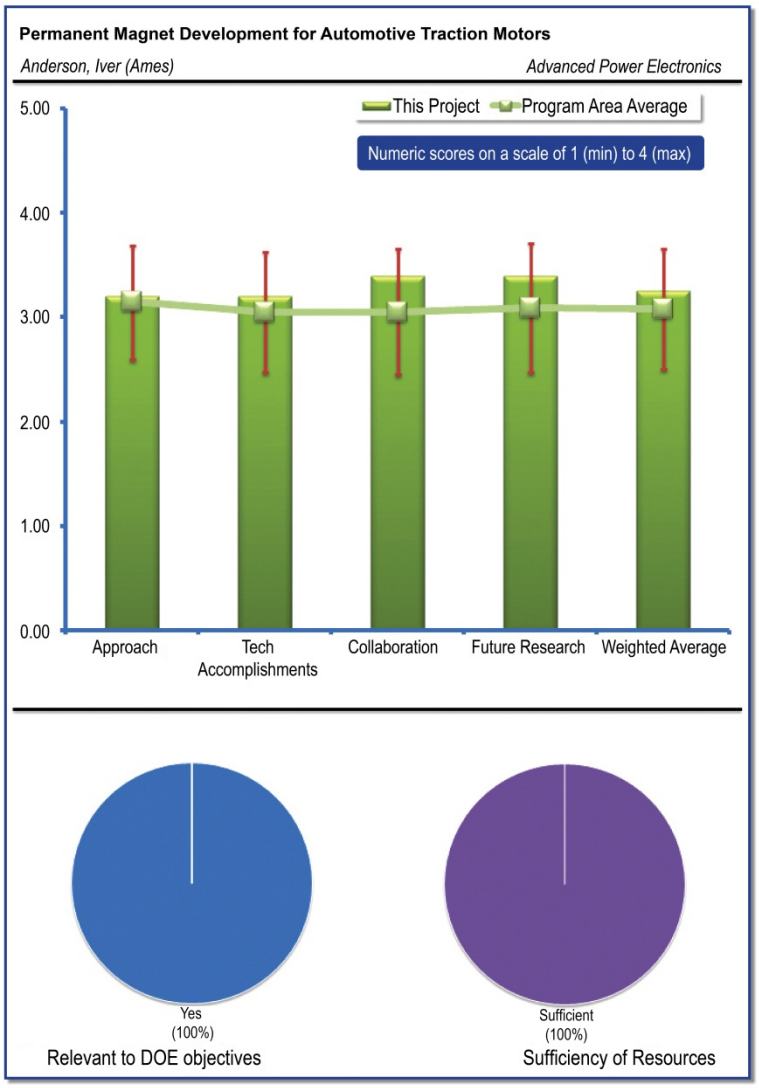
Permanent Magnet Development for Automotive Traction Motors: Anderson, Iver (Ames) – ape015

Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

All reviewer comments to this question were positive. One commenter simply stated that replacement and minimization of rare-earth magnets is key for electrification success in automotive. A second reviewer noted that the project focuses on reducing or eliminating the rare earth permanent magnet materials content which can have a significant impact on reducing the cost. Another reviewer explained that permanent magnet machines dominate vehicle electrification, and work to improve the technology and reduce/eliminate dependency on China for these materials supports overall DOE objectives. The final commenter had detailed comments, stating that rare-earth permanent magnet materials are a main cost driver in electric machines. The researcher's goal is to develop new magnet materials with reduced heavy rare-earth content or to eliminate the rare-earth magnet material entirely by using different alloys. The reviewer agreed that both developments would reduce the cost of permanent magnets and would therefore accelerate the broad implementation of electric machines in vehicles.



Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Responses to this question were generally positive, but mixed with suggested scope additions to improve the project. One commenter expressed that the program addresses the issues directly: the elimination of dependence on materials that are difficult to obtain. The reviewer cautioned that a possible research approach deficiency is not integrating the magnet work with motor development and prototype work at an early stage of the work. Another person commented that the researchers have a good approach trying to address permanent magnets with reduced rare earth content as well as non-rare earth magnets. One reviewer noted that it seems that ferrite magnet materials have been excluded from the study up to now. The reviewer asked whether there are any plans to look into this topic at a later point in time. The final reviewer observed that the approach for reducing permanent magnet costs in this project follows two different paths. One path is the reduction or replacement of heavy rare-earth materials like Dysprosium while still maintaining high-coercivity which is needed for acceptable thermal performance of the permanent magnets. The second path is the development of rare-earth free permanent magnet materials with suitable performance. This part of the project looks in depth into the improvement of AlNiCo and the development of new alloys like Fe-Co-W.

QUESTION 3: CHARACTERIZE YOUR UNDERSTANDING OF THE TECHNICAL ACCOMPLISHMENTS AND PROGRESS TOWARD OVERALL PROJECT AND DOE GOALS.

Comments to this question were generally positive. One person remarked that the project shows good progress in terms of achieving a better understanding of permanent magnet metallurgy both for rare-earth and non-rare earth magnet materials. The work in the area of reduced Dysprosium content shows progress with promising results for $(BH)_{max}$ and high temperature performance. The reviewer asked when the achieved results will be transferred into an electric machine design in order to prove the applicability. Another person acknowledged that dysprosium-elimination and iron-cobalt magnet efforts are at their beginning stages, but early activities provide optimism that the work is getting a good start. Another reviewer agreed, stating that the Beyond-Rare-Earth part of the project is still in an early stage although it shows a few promising aspects. The reviewer added that if the significant improvement of the coercivity of AlNiCo would become reality, it would be a major breakthrough. The last reviewer agreed that good progress has been made, but felt that more understanding of how the proposed magnets compare to the state-of-the-art is needed.

QUESTION 4: WHAT IS YOUR ASSESSMENT OF THE LEVEL OF COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS?

Comments to this question were generally positive. One reviewer observed that the project has an impressive number of collaborators with different expertise. The reviewer felt that this will potentially accelerate the development of new magnet materials if the lead researchers are able to coordinate all the contributions in an effective manner. Another person also acknowledged that the collaborator list is long and diverse. The reviewer remarked that it will be important to manage the work (not spread the team too thin) by weighing the value of the feedback from this group of participants. The final reviewer cautioned that even though there is a very long list of collaborators, it is not clear what are their actual contributions, so this needs to be made clearer.

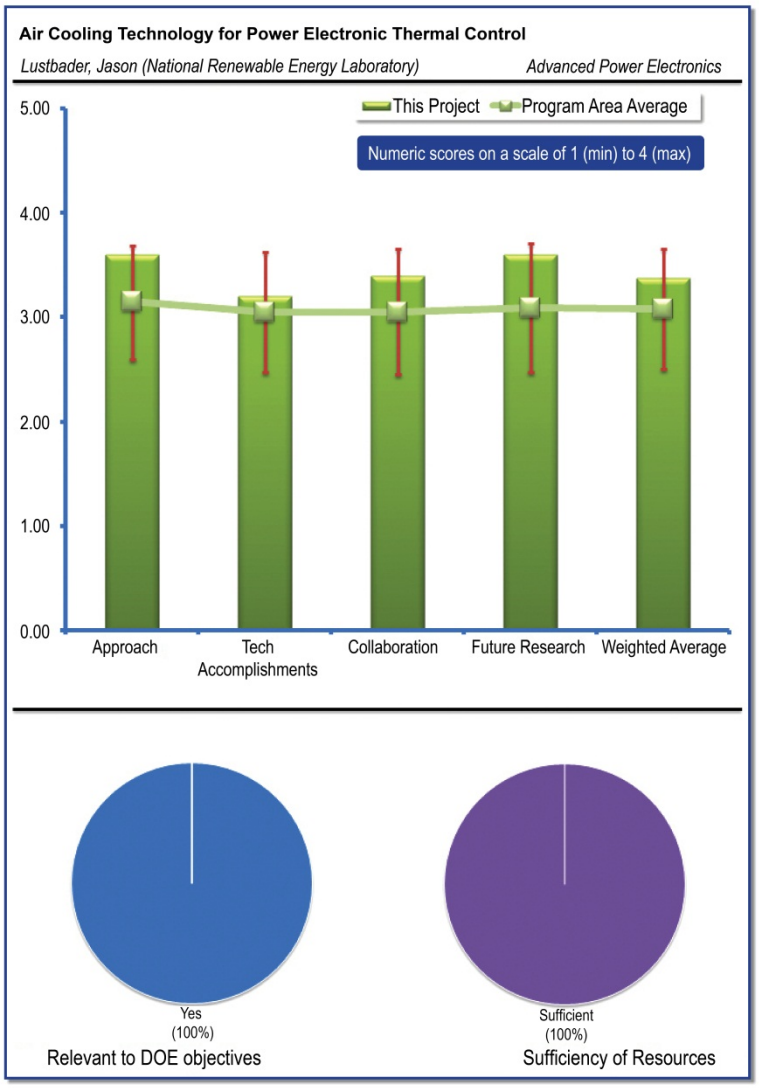
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

One person commented that the future work to eliminate dysprosium and create higher coercivity nickel-cobalt magnet alloys is important and has high value. The reviewer felt that the ideas were presented that support both activities. Another reviewer observed that the researchers seem to have a clear plan on how to move forward with their current work. The final reviewer cautioned that before proceeding further with all the proposed areas, quantifying the impact of the theoretical properties of the proposed magnets on an actual motor performance would be highly desirable and recommended.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

No reviewer provided a comment to this question.

Air Cooling Technology for Power Electronic Thermal Control: Lustbader, Jason (National Renewable Energy Laboratory) – ape019



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

One person commented that thermal cooling is one of the most important aspects to meeting the DOE goals and it is a significant cost factor. The reviewer acknowledged that this project addresses novel cooling methods. Another reviewer noted that air-cooling has the potential to reduce the cost of the PE in the vehicle thus increasing affordability. Another person commented that the elimination of parasitic loads, such as dedicated liquid coolant loops for electronics cooling, provide both direct and indirect reduction of work required by the PCU, ICE, or generic bus energy conversion. Thus, additional fuel consumption savings is realized, which may also be augmented by volume and weight reductions. The magnitude of this impact will be borne out by the outcome of this and other similar trade studies of vehicle subsystems. The reviewer felt that the primary advantage of this project is the system level approach to subsystem optimization, which increases the relevance of the study outcome results. The final reviewer agreed that lower cost of power electronics helps to enable the market for power electronics; however, the reviewer cautioned that larger package volumes for power electronics modules may limit application opportunities.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Comments to this question were mixed, with some lauding the approach, while others were more critical and provided suggested guidance. One reviewer stated that the approach is a multi-dimensional study which is very comprehensive and balanced. It looks at a wide field of new technologies. The reviewer felt that the researchers appear to have all the control variables under consideration. Another reviewer remarked that the researchers presented one of the most well organized and intentional work plans observed during the review. The reviewer felt that each task was highly organized and cooperatively dovetailed with the other tasks in the project leading to an overall project structure which is highly likely to achieve a relevant outcome. The reviewer asked specifically, which components, if any, can be satisfactorily be managed using ambient air-cooling directly. The reviewer concluded by offering kudos to Mr. Lustbader, the PI. One commenter expressed that the approach focus on technical barriers is very good, but other issues related to side-effects of cooling method cannot be ignored. The side effects include audible noise and additional cost of cabling that different location may cause. One reviewer said that the researcher's approach is good, but it is not clear in an engineering sense what the researchers are designing to. Another reviewer simply stated that the researcher needs to pick an application for comparison. One person suggested that the researchers need to understand the heat flow capacity by air-cooling method for a 30 kW inverter system, the cost for the balance of the air-cooled system. They concluded by mentioning that the audible noise needs to be studied. The final

reviewer had detailed criticisms and suggestions to improve the approach. The reviewer remarked that from a systems approach please state the DOE targets for an air-cooled system and how your approach can meet those requirements. They suggested that the researchers refer to the previous FOA for a power electronics air-cooled inverter approach as an example; from that example provide your thermal design target, cooling design target, and package design target. Once that is done, discuss your proposed implementation to meet those targets.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer commented that the results demonstrate a high degree of coherent focus on the proposed task plan and were obviously accomplished with a high degree of fidelity and confidence in these results. This reviewer felt that the project appears to be on schedule and well managed and executed. Another reviewer noted that so far the work is just starting to experiment with some new techniques such synthetic jets, but this is very promising. The reviewer remarked that the subject is so broad that in the future there will be more down selection of promising methods. Another reviewer stated that the progress on air-cooling is good and is using interesting ideas. They explained that air-cooling is currently being used in HEVs and BEVs with good success, but not without problems. The reviewer pointed out that concerns include investigating effects of time on the performance, i.e., how does fouling impact the air-cooling path (dust, etc.) as well as audible noise. The final reviewer agreed the researchers are off to a good start, but criticized that the engineering targets the investigators are trying to address are not clear.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

Comments to this question were mixed. One person remarked that there was very good collaboration with other institutions and companies. However, another reviewer commented that it was not clear if there was any collaboration with vehicle manufacturers. The final reviewer offered that the only suggestion for improvement here might be to consult with vehicle and power electronics manufacturers for environmental boundary conditions and dynamic heating effects, respectively.

Question 5: Has the project 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?

Comments to this question were generally positive, with two reviewers offering suggested improvements. The first reviewer stated that the work plan for future work encompasses all the needed systems, components, and technologies. Another reviewer commented that the proposed efforts for the balance of this year, and in the out-years, reflects the highly organized structure of this project. The reviewer also pointed out that leveraging prior results with a focus on the critical aspects of the study are obviously in place. Another reviewer commented that the approach is clear but need some specific design targets to address, so the researchers should state what these design targets are. The last reviewer to comment expressed that the plans looked good and they are focusing on the technical issues mentioned. Need to broaden the scope a little when some of the fundamental issues are solved.

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

No reviewer provided a comment to this question.

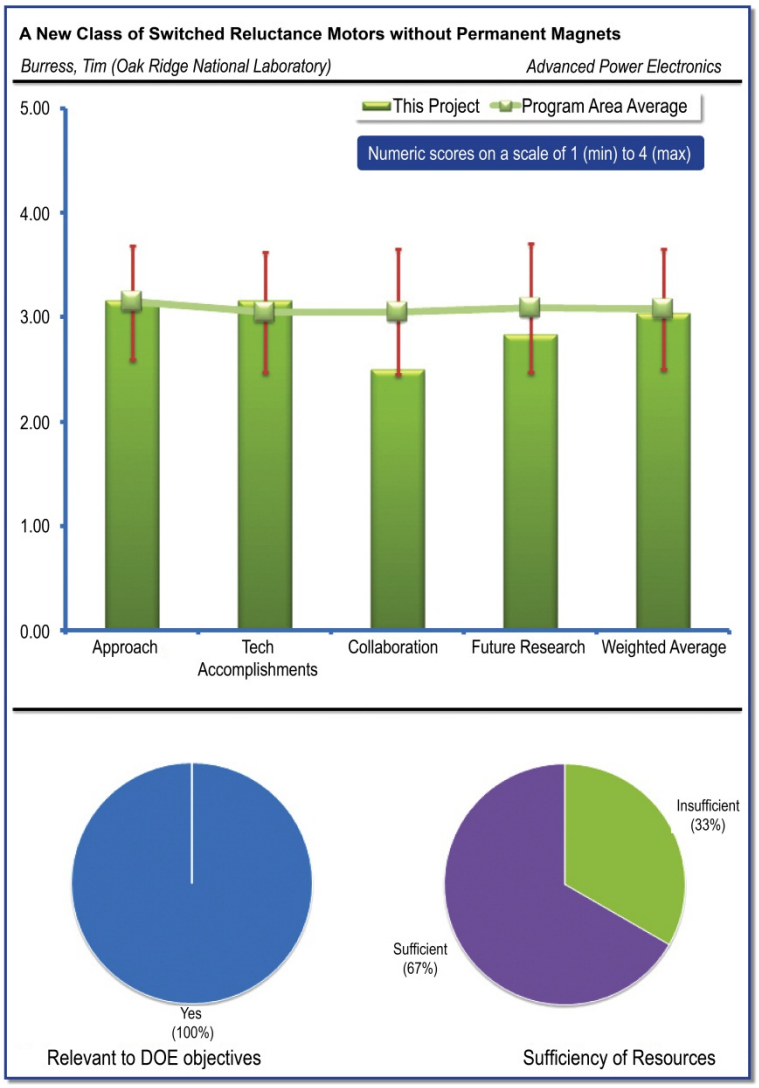
A New Class of Switched Reluctance Motors without Permanent Magnets: Burress, Tim (Oak Ridge National Laboratory) – ape020

Reviewer Sample Size

This project had a total of six reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

Comments to this question were all positive, but only one person specifically mentioned the project supporting DOE goals. One reviewer simply noted that this project aims to produce a motor without rare earth magnets. Another reviewer had a similar reaction, commenting that the motor technology is novel and addresses the current supply/cost issue with rare-earth magnets by eliminating them from this motor. One reviewer remarked that switched reluctance machines do not need permanent magnets and have the potential of reducing the cost of electric drive systems, which supports the DOE objective. Another person described that the project proposes a new class of switched reluctance motors which potentially can have the same performance as rare-earth PM motors. The reviewer added that this potentially can cause a significant reduction in the motor's cost as well as eliminate the dependence on rare earth permanent magnets. The final reviewer to comment pointed out that the project will address fundamental torque ripple and acoustic noise issue which have prevented the use of switched reluctance machines.



Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Comments to this question were generally positive, with some questions being raised. One reviewer commented that the researchers' approach seems good in terms of doing analysis/simulation then moving towards building and testing a prototype. The reviewer noted that the accuracy and how detailed the analysis/simulations are need to be revisited. Another reviewer remarked that the program is well designed in terms of the design possibilities survey, modeling, and prototype fabrication/test activities. It appeared to this reviewer that this is an innovative version of a switched reluctance machine. Another reviewer commented that this is fresh approach to looking at switched reluctance motors; the initial results pointed to some new and innovative concepts which were not explored previously. The final reviewer had detailed comments, indicating that the project attempts to address the main issues of switched reluctance machines which are torque ripple and acoustic noise. The reviewer added that it was mentioned that several novel switched reluctance machine concepts have been investigated in detail before the most promising concept has been chosen for optimization and prototype build. Unfortunately, not many details about the investigated variants are provided. The reviewer concluded by noting that a prototype machine was built and tests are underway which is necessary to prove the claimed benefits.

QUESTION 3: CHARACTERIZE YOUR UNDERSTANDING OF THE TECHNICAL ACCOMPLISHMENTS AND PROGRESS TOWARD OVERALL PROJECT AND DOE GOALS.

Reactions to this question were mixed. One reviewer expressed that good progress has been made in terms of building a prototype but there are several issues need to be resolved: (1) The fact that the measured torque is ~75% of predictions needs to be resolved, (2) More detailed loss/efficiency analysis is needed. Mechanical losses especially windage should be included, (3) It is not clear how torque ripple and noise will be verified by measurements, (4) The comparison to the DOE specs need to be on the basis of the required peak torque at the required speed, (5) What is the assumed coolant inlet temperature?, and (6) Has any detailed thermal performance been performed? Another reviewer described that testing has begun and issues are overcome as they occur. They added that test results at power and speed will occur shortly, given the progress made to date. One commenter said that the tests on the prototype machine look promising in respect to torque ripple and noise. The reviewer went on to say that the real test will be at higher torque levels where acoustic modalities occur. They concluded by mentioning that one thing that is promising is that torque ripple can be varied electronically so that higher power can be achieved at high speeds where ripple is not noticeable (but noise is). Another person stated that the researchers need to elaborate more on the unconventional design to reduce the torque ripple. One reviewer reported that the focus of the simulations seems to be on the main issues of switched reluctance machines which are torque ripple and vibrations, but this is not enough. The reviewer also noted that an additional part of the work has been the development of general machine design and controls optimization tools which is an impressive achievement. The final reviewer pointed out that the researchers state that extensive simulations have been conducted, but only very few results are presented. They added that no statements about loss and efficiency simulations and performance curves under consideration of thermal limits were presented.

QUESTION 4: WHAT IS YOUR ASSESSMENT OF THE LEVEL OF COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS?

One reviewer explained that most of the work has been conducted by the principal investigators. The reviewer felt that additional support from a motor supplier regarding manufacturability and cost of the novel machine design would have been helpful. Another person had similar observations, stating that it looks like mostly internal people working on the project. There should be more outside participation with switched reluctance experts or companies that make switched reluctance motors. One reviewer indicated that there was some level of collaboration with MotorSolver, but suggested that more collaboration with OEMs and people in industry with switched reluctance experience needs to increase to guide this effort in the right direction. The final person commented that the modeling and machine design partners are good, but that the lack of manufacturing and controls partners is a deficiency of this program.

QUESTION 5: HAS THE PROJECT 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?

One person commented that even without partners to help address future challenges, the work planned should quantify the performance of this new motor. Another person simply stated that they felt that future testing will show the direction for future research. One reviewer commented that it seems as if there is still a lot of work ahead of the researchers although there is not much time left until the project deadline. The reviewer offered that this may be a wrong impression due to the fact that not much detailed information is provided about the status and the plans to address potential issues. The reviewer added that the control of switched reluctance machines plays a major role in their performance and this is also not explained in enough detail so far. The final reviewer provided suggestions that full testing of the prototype is necessary as well as comparison to predictions and refining the design/analysis process based on measurements.

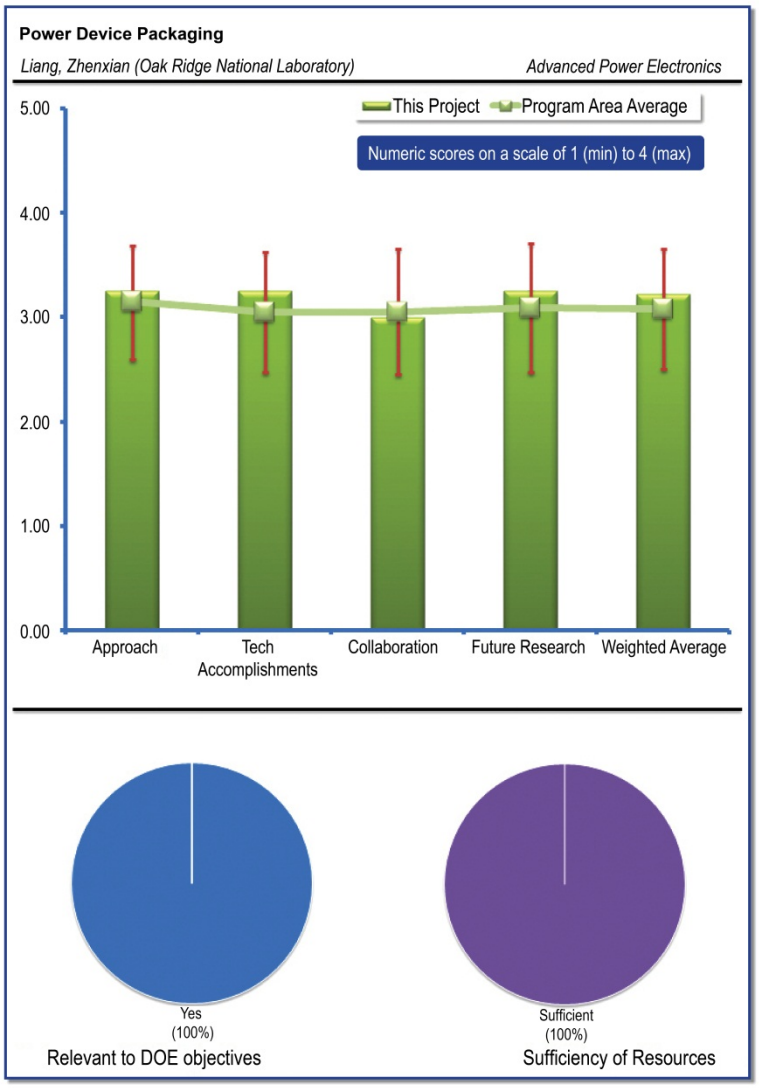
QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

No reviewer provided a comment to this question.

Power Device Packaging: Liang, Zhenxian (Oak Ridge National Laboratory) – ape023

Reviewer Sample Size

This project had a total of four reviewers.



Question 1: Does this project support the overall DOE objectives? Why or why not?

The first reviewer commented that the improvement of power device packaging in terms of cost and power density will enable the design of smaller inverters with lower costs; this supports the DOE objectives. Another reviewer agreed, stating that the power device package has a tremendous impact on the cost and performance of the power electronics and this project is addressing the package. The third reviewer felt that it was implied but not stated, that improving power density, manufacturability and cost of power modules helps to lower the cost of power electronics which helps to enable the market for HEVs, PHEVs, and FCVs.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

One reviewer indicated that having the ability to design and build packages in house is a great advantage and will allow fast turnaround on potential solutions to problems discovered. Another reviewer agreed, saying that the development of power electronics packaging capabilities at a National Lab is a good approach as this permits the faster investigation of novel ideas without the immediate involvement of suppliers. The benchmarking of the state of the art technologies is very valuable. The third reviewer also agreed, stating that having a power module assembly process and access to failure analysis labs allows the capability to compare different power module configurations. The Automotive power module design/cost analysis tool is a good metric for comparing the different power modules currently used today. However, it was difficult to understand what they were doing with their new power module design since the work is under patent review. The reviewer felt that quantifying the goals by using the analysis tool to show what others have done versus what the project predicts the new design will achieve and felt that this approach to quantification of goals should be doable without having to reveal details of the design.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer indicated that the progress to date setting up the lab was great. Another reviewer indicated that the power module design analysis tool is an interesting approach to comparing different designs. The reviewer wanted to know if it was possible to present a chart - based on the tool - that shows the relative cost, reliability and power loss of the modules Oak Ridge National Laboratory (ORNL) has analyzed? The third reviewer felt that the accomplishments in terms of the benchmarking activity are very good both for the electrical and the mechanical analysis but that the progress of the new device packaging concept is difficult to evaluate as very few

details are provided. In addition, the reviewer felt that the claims of improvement are impressive but not proven at this point in time and that the support of other programs is of high value.

QUESTION 4: WHAT IS YOUR ASSESSMENT OF THE LEVEL OF COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS?

One reviewer noted that the collaboration is purely on a National Lab / university basis. Additional support and input from suppliers or Original Equipment Manufacturers (OEMs) would enhance the project results in terms of high volume production manufacturability. Another reviewer stated that it would be positive to see this project join with *Electro-thermal-mechanical Simulation and Reliability for Plug-in Vehicle Converters and Inverters* (Allen Hefner of NIST) and *Physics of Failure of Electrical Interconnects* (Doug DeVoto of NREL) to take advantage of the failure modeling and performance modeling. This reviewer thought that joining with these two projects would create a closed loop path for package design as well as improve the modeling accuracy.

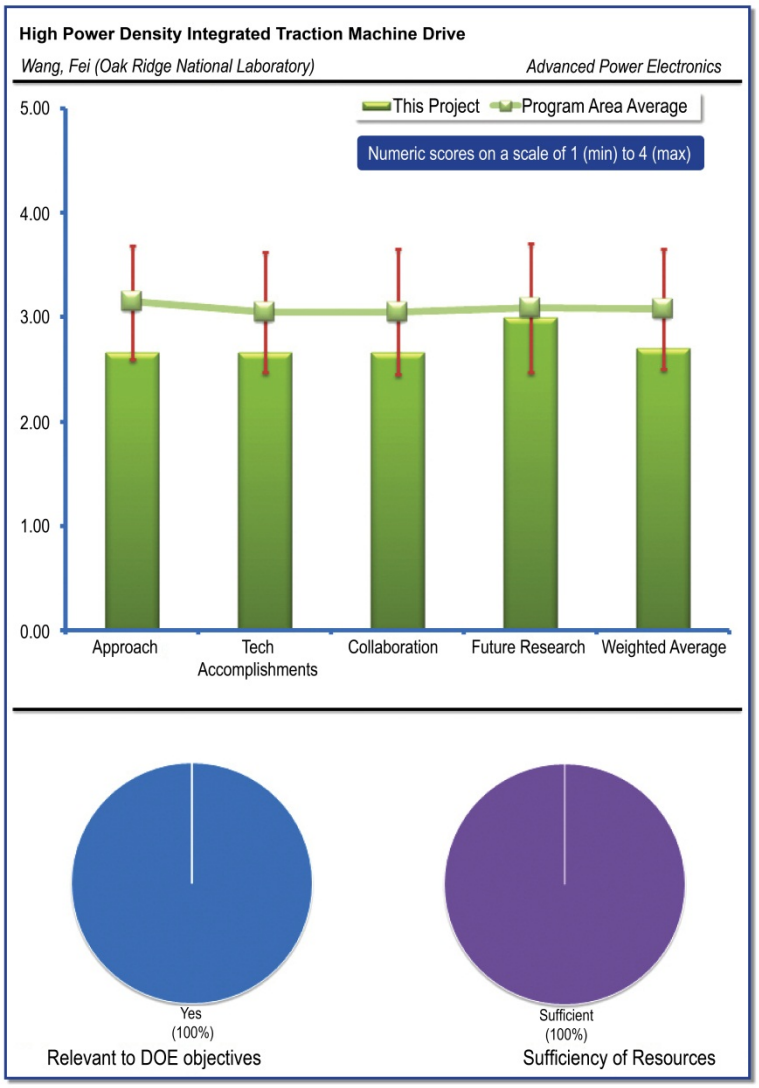
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

One reviewer noted that the research had great potential if collaboration with other projects occurs. Another reviewer felt that the answer to this question was hard to determine since the details of the power module concept have not been presented but that the competitive assessment is always interesting. The third reviewer felt that the researchers have a reasonable plan for the future work. It is mentioned that in FY12 inverter-level packaging studies will be started. The reviewer noted that this seems to be outside of the original scope of the project and will hopefully not consume too many resources. It might be better to focus on the device packaging activities.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

All four reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

High Power Density Integrated Traction Machine Drive: Wang, Fei (Oak Ridge National Laboratory) - ape024



Reviewer Sample Size

This project had a total of three reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

One reviewer stated that the goal of the project is to integrate the power electronics with the motor in a modular design which would result in a high power density. Moreover, the power electronics maximum operating temperature will be increased. Both measures could potentially accelerate the implementation of electric drive systems in vehicles and this supports the DOE objective. Another reviewer indicated that integrating the motor and inverter can have a significant impact on reducing the system cost.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

One reviewer indicated that the researchers try to integrate a variety of innovations into one novel traction system. These are a multi-phase motor with modular design, a modular inverter with new packaging which is physically integrated with the motor, higher maximum junction temperature of the IGBT and a modular controller design which would provide better fault tolerance. The reviewer felt that it was an honorable approach, but that it might be better to separate the innovations on the subsystem level from the physical integration of motor and inverter because some of the innovations have a high value in itself (e.g. the increased junction temperature or the multi-phase motor). Moreover, the reviewer noted that the axial integration of the inverter and motor is not the preferred solution for transmission integrated hybrid drivetrains. A reviewer was not convinced that the 6-phase machine is the way to go. The reviewer noted that it adds significant complexity to the system and questioned whether the increase in number of devices was justified. Also, in order to achieve fault tolerance, the reviewer felt that the winding configuration needs to be modified to single-layer tooth winding. Additionally, the reviewer felt the key novelty is the packaging and integration part which could be shown first on a 3-phase machine before tackling the fault-tolerance issue. A reviewer noted concern about the location proposed to mount the inverter modules. Additionally, a reviewer noted concerns with scalability. This reviewer felt that, as the effort is currently targeting a 10 kW prototype, it has to be shown that there is no scale-up challenges in terms of packaging or any other aspect. One reviewer noted the need to understand the thermal and vibration impact on inverter mounting location.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer felt that good progress was made on the device and packaging side. In addition, the reviewer felt that the selection of the 6-phase motor was questionable and noted that no information was provided about the cooling mechanism and whether the motor is

designed to meet the 105°C requirement. Another reviewer noted that the accomplishments on the motor development side are difficult to evaluate because little detail is provided. The reviewer wanted to know what the simulated performance of the multi-phase machine was and how it compares to the DOE requirements. Additionally, the reviewer asked what the specific advantages of the modular design in terms of cost and performance were. The reviewer felt that the progress for the power electronics is described in more detail and first test results for the module are promising and that the device packaging seems to be on a good way, but the overall integration of motor and inverter seems to be in a very early stage, and that no further details were provided.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

One reviewer felt that the collaboration with the University of Wisconsin was good. Another reviewer noted that there is collaboration with two universities but it seems as if no industry partner is involved. The reviewer felt that an industry partner might be necessary for better guidelines of which packaging concepts the industry is interested in. One reviewer left no comments.

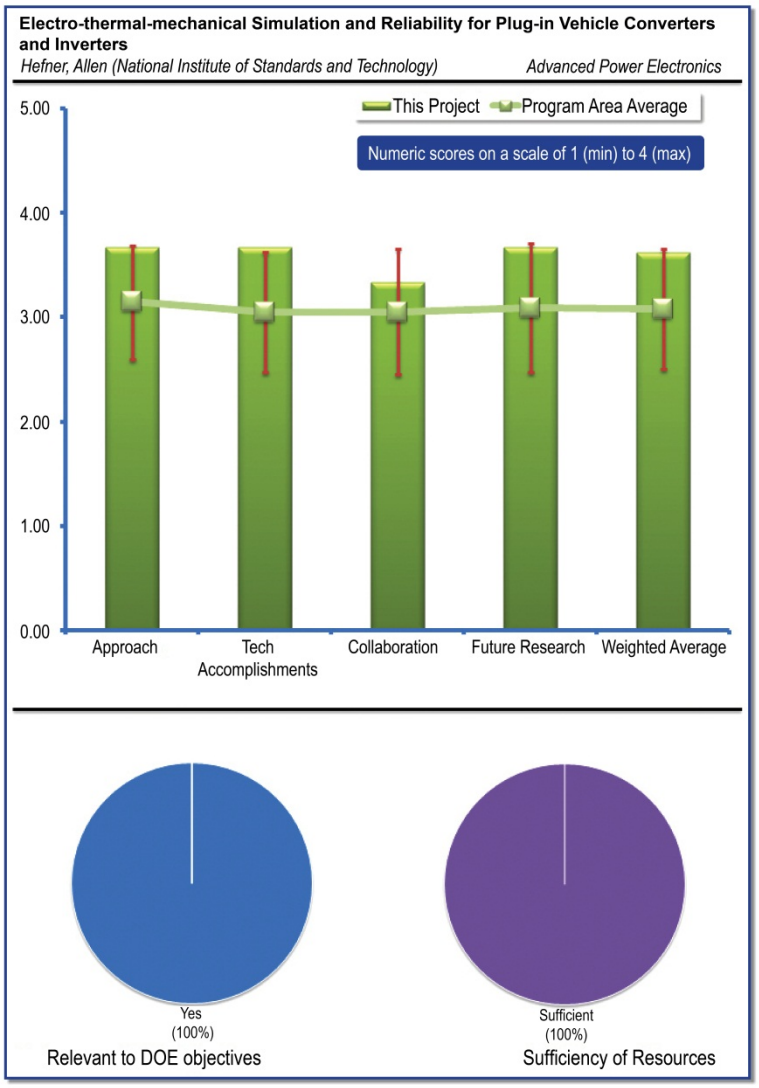
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One reviewer felt that it is a good approach to first prove the feasibility of the new concepts through the planned test of the 10kW system. The reviewer stated that an estimation of the manufacturing cost of the integrated system is definitely needed for the next review because the cost impact of the new concept is unclear at this point in time. Another reviewer noted that the building and testing of the 10kW system is a critical deliverable in terms of highlighting any potential issues. The reviewer felt that it was not clear how the testing will be performed at 105 °C.

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

All three reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

Electro-thermal-mechanical Simulation and Reliability for Plug-in Vehicle Converters and Inverters: Hefner, Allen (National Institute of Standards and Technology) - ape026



Reviewer Sample Size

This project had a total of three reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

One reviewer noted that it is important to understand the thermal electrical characteristics of power electronics. Another reviewer stated the following: one of the more subtle factors facing developers of optimized hybrid PEV technologies is the issue of understanding and managing the dynamic heat transfer and thermal management of power electronic subsystems. As volumetric and mass power density objectives become more aggressive, heat capacity and the margin for power device junction temperature management decrease. Thus, a critical understanding of dynamic, non-equilibrium thermal transients in these systems is crucial to the fielding of reliable electrical powered components. Both efficiency and catastrophic failure prevention necessitate this consideration. The subject project is outstanding in its inclusion of these considerations in power device and module design and analysis. Legacy steady state analysis of power components will not provide the performance or reliability required to successfully deploy these vehicular systems with this consideration. The subject project includes and leverages this critical consideration and thus provides the framework for key electrical component analysis and development.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

One reviewer stated that the investigator was building models of all the major thermal parts and interfaces found in power electronics. The investigator is creating these in Saber which, in the reviewer's opinion, is an excellent analytical tool. Another reviewer indicated that the electro-thermo-mechanical modeling project includes the requisite physics-based modeling required to enable critical consideration of technologies being developed for reliable vehicle applications. The reviewer felt that the use of modeling validation with power electronic component hardware characterization was excellent and that the goal of bond fatigue and failure predictions will be important to module and packaged power device development.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer noted that the work so far looks to expand our understanding of the static and dynamic thermal characteristics of power electronics. The reviewer believes that this is a new approach and can lead to improved thermal and electrical design. Another reviewer felt that progress to date was on-target with APEEM goals, objectives, and schedules. An application of the physics-based

models to power packages and modules developed by other contractors reflects the relevance of this activity and the potential for it to measurably impact the evolving development of these key electronic components.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

One reviewer stated that the collaboration structure with the hardware from other projects being evaluated using the dynamic models was excellent. In addition, the goal to predict thermal fatigue of solders and wire bonds will provide valuable feedback to component developers involved. One reviewer noted that the Principal Investigator is working with many companies to develop the device models.

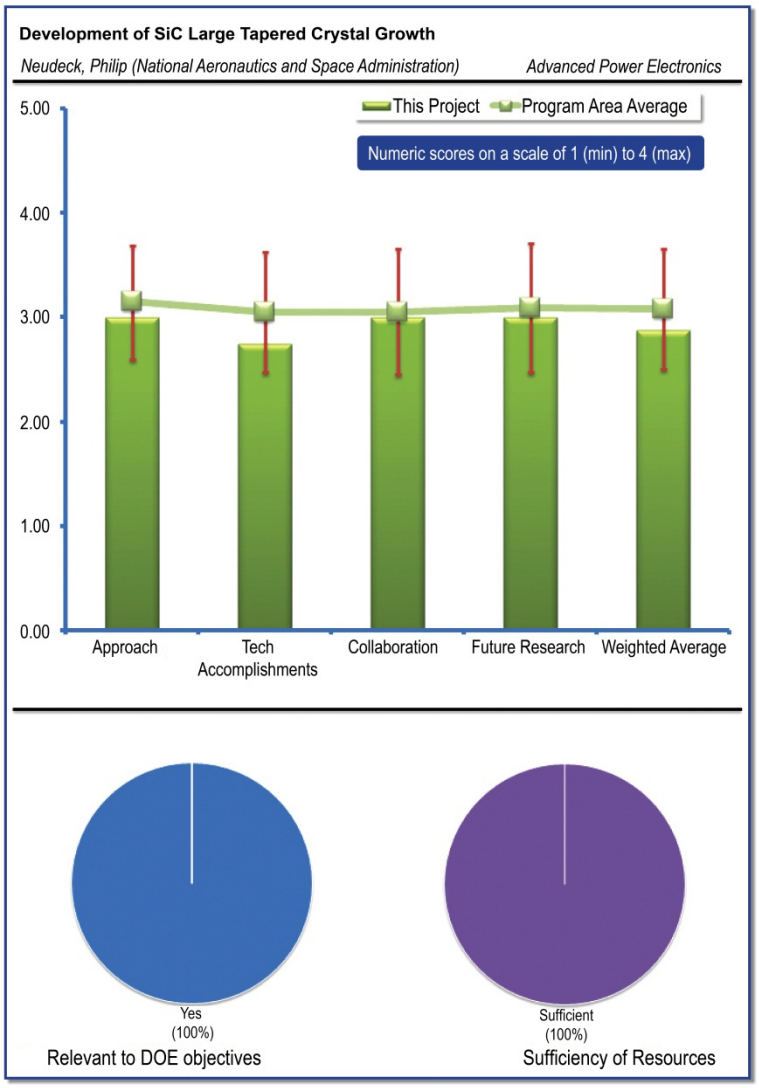
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One reviewer indicated that the prospect for valuable positive impact to the overall electrical component development portfolio is very high. The reviewer felt that successful validation of a developed thermo-mechanical prediction tool for reliability projections is a much needed capability if cost-effective vehicle subsystems are to be successfully developed.

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

All three reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

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



Reviewer Sample Size

This project had a total of four reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

One reviewer stated that the potential impact to DOE objectives for this project are longer term, but prospectively significant. If the novel crystal growth technology being pursued is successfully demonstrated, a dramatic impact to Silicon Carbide (SiC) power device yield (meaning cost) and performance (i.e. efficiency which translates into greater fuel displacement) may be realized. Thus, while this project is a fundamental science type project – and thus higher risk – it can potentially have a significant impact on hybrid and PEV vehicle fuel consumption. Another reviewer noted that the project presumes that defects are inherent in existing SiC material growth approach and that a completely new approach is required to produce material that can enable devices that will meet VTP program goals. The project claims that the new approach will lead to an improved material which will lead to 100X improvement in material defects and 2X lower cost in SiC devices. Lower cost SiC devices may lead to propulsion inverters with lower cost, weight, and volume. A third reviewer stated that improving the efficiency of inverters and converts directly improves PEV and HEV. One area for improvement in those components is the electronic devices themselves. Using SiC electronics will help with that improvement; however, SiC is hampered by constraints that this project will help relax.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer noted that there was a very well organized research task structure, with requisite focus and emphasis on the critical technical barriers of fiber fabrication and floating solvent growth demonstration of high quality crystals. If demonstrated successfully, the project will provide tangible evidence for the potential utility of the investigated crystal growth approach. Another reviewer noted that this project takes a novel approach to creating crystals which not used in industry today; the reviewer feels it has the potential to change how things are done and is not just an evolutionary step. A third reviewer noted that the project claims that devices made with existing SiC materials do not meet fundamental limit expected for devices made with SiC. The reviewer indicated that this presumption is disputed by other experts. The reviewer also noted that the project strives to develop a new crystal growth method that will compete with existing boule growth methods. As there has been considerable investment over many years in the current approaches, this project represents a very high risk long term prospect that might meet and exceed the capabilities of existing SiC boule growth approaches.

QUESTION 3: CHARACTERIZE YOUR UNDERSTANDING OF THE TECHNICAL ACCOMPLISHMENTS AND PROGRESS TOWARD OVERALL PROJECT AND DOE GOALS.

One reviewer noted that real world demonstration of planned steps has happened as planned. Another reviewer felt that progress has been slow to this point, although reactor design, build, and initial experiment evaluation are very laborious and time consuming activities. The reviewer also indicated that, now that the initial source melt and seed crystal wetting experiments have been demonstrated, there should be rapid progress leading to grown crystal evaluations sufficient to determine process potential. A third reviewer noted that the approach proposed by the project requires two achievements; first the growth of a one-dimensional SiC crystal fiber, and second the two-dimensional radial crystal growth of SiC using the one-dimensional fiber as seed. The reviewer indicated that there are no crystal quality metrics for the program. The reviewer does feel that progress has been made since both linear and radial growth have been demonstrated: Laser heated float zone assisted fiber growth equipment complied, and ave grown SiC fiber from pseudo seed made from commercial wafer. Radial growth has been demonstrated using pseudo fiber. However, the reviewer feels that the quality of the material and the prospects of producing a boule or appreciable size are very uncertain.

QUESTION 4: WHAT IS YOUR ASSESSMENT OF THE LEVEL OF COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS?

One reviewer indicated that there are a number of collaborations with leaders in SiC crystal science within NASA and elsewhere. The competency of the project leader and his associates is the major strength of the project. Another reviewer indicated that there was good connection with the SUNY for critical crystal characterization feedback. The reviewer felt that it might have been advantageous to have included crystal growth expertise from Carnegie Mellon or another university program with a strong growth program history. A third reviewer indicated disappointment that collaboration seemed to be primarily with NASA.

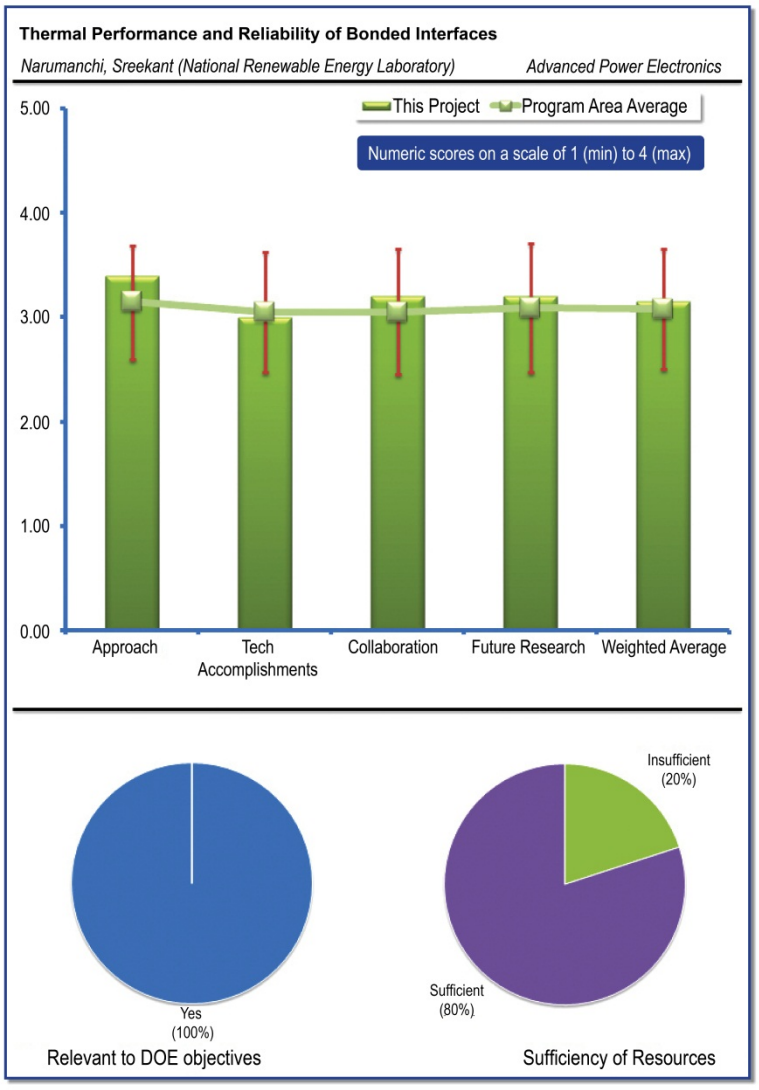
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

One reviewer noted that the future planning was appropriate; the reviewer noted that after NASA has proven the fundamentals, it should initiate another project with more collaborators. Another reviewer indicated that NASA, if nothing else, has been highly focused on this approach to crystal growth for several years following their demonstration of single dislocation growth processes of in-plane SiC crystals. Thus, the project plan is highly aligned with their prior successes and they have an outstanding understanding of the technical barriers and practical obstacles which need to be overcome. A third reviewer indicated that the project plans to continue analysis of the material and to continue to improve growth rate and size of the crystal. Additionally, the reviewer noted that no metrics were given about crystal quality required at various stages of development to meet the stated goal of better material quality and lower cost than existing boule growth methods. The fourth reviewer remarked that the stated future plan for the project is if both fiber and radial growth processes demonstrated as viable in this project, initiate follow-on project (with more development partners and funding) to build and demonstrate “full-up” LTC boucle production prototype. This reviewer noted that there were no material metrics, timeline, or cost estimates of the research and development required to meet the stated goals of better material quality and lower cost than existing approaches.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

All four reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

Thermal Performance and Reliability of Bonded Interfaces: Narumanchi, Sreekant (National Renewable Energy Laboratory) - ape028



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

A reviewer noted that this project has the possibility of improving the efficiency of the major heat generators inside inverters and converters. Another reviewer noted that this project addresses key joining issues that provides for thermal performance and reliability increases, and cost reduction. The third reviewer noted that improving thermal performance can reduce Si size, resulting in lower cost inverters. Reaching the target spec for thermal resistance of the bonded interface material (BIM) will also allow for more tolerance and robustness in the assembly process of the power stage.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

One reviewer noted that the combination of modeling and comparing to real world parameters is important. The approach could be improved by considering failure/degradation modes that are unique to various BIMs. A reviewer indicated that the quality of these joints are dependent not only the materials being joined and type of joint, but the process that was used. The reviewer was concerned that not all these factors were being tracked and understood. A reviewer indicated that thermal shock testing may be an issue for materials that require a long dwell time between cycles. The reviewer was curious about how that testing can be accelerated for long dwell time, slow creep, materials. The reviewer also indicated that this approach can provide the initial design starting junction temperature of the power device which will be very useful.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer noted that collecting thermal cycle data is a long process in terms of time but that the data are needed. Another reviewer agreed, indicating that it was good to see real world results.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

A reviewer indicated that using a variety of outside sources helps to better define the problem and focus the results.

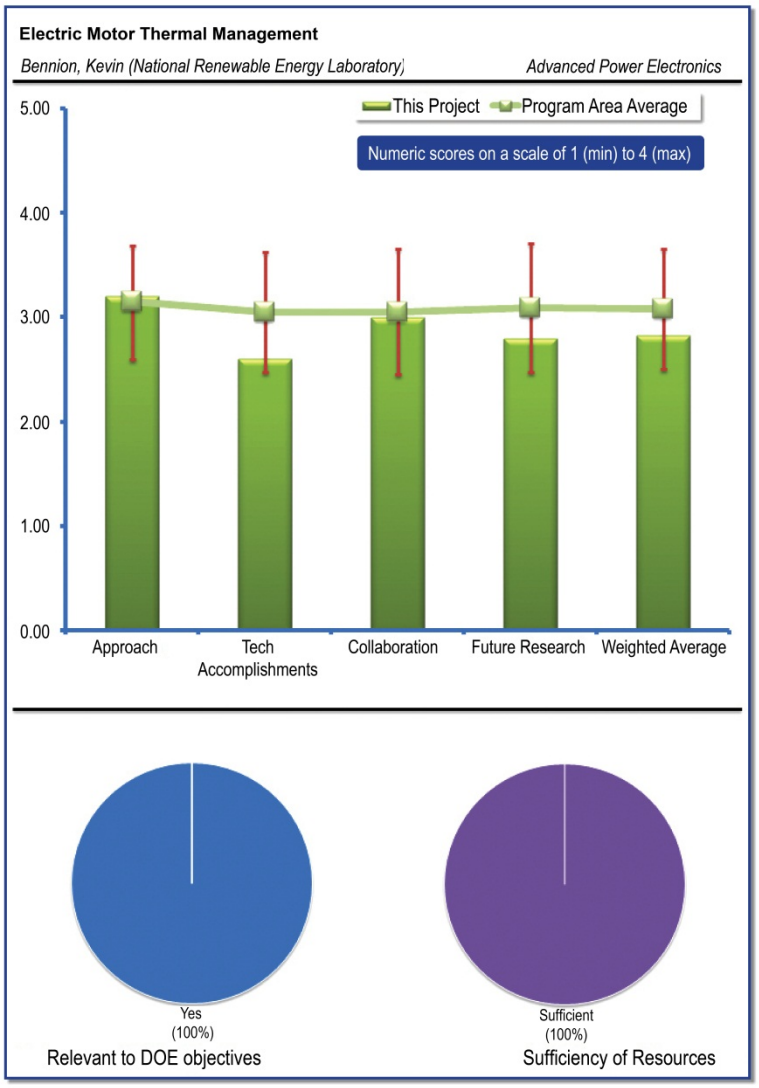
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

A reviewer noted that the plan is a good one, and that it was important to stay on the plan. Another reviewer noted that the work is well defined and bounded.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

Four of five reviewers felt that the resources for the project were sufficient to achieve the stated milestones in a timely fashion. One reviewer felt that the funds were insufficient.

Electric Motor Thermal Management: Bennion, Kevin (National Renewable Energy Laboratory) - ape030



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

A reviewer stated that the better understanding and consequently improvement of the thermal limits of electric motors enables the design of motors with higher power density. The reviewer felt that this supports the DOE objective. Another reviewer noted that thermal management is a key enabler to meeting the traction motor performance targets. A third reviewer indicated that motor thermal management limits the output power, affects the size, and influences the cost of electric propulsion motors. A fourth reviewer stated that thermal management is important to achieving the DOE goals.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer stated that the systematic approach with analysis of loss mechanisms in motors, packaging impact, cooling technologies and balance of the complete system is excellent. The reviewer also felt that the link into the Vehicle Technologies Program project "Combined Heating/Cooling Loops in Advanced Vehicles" is very valuable for the determination of overall system impacts. A reviewer stated that performing a literature review is a good starting point. The reviewer noted that the challenge is that this topic has been thoroughly investigated over the years and it may be challenging to identify what areas can be improved and how. The reviewer also indicated that a baseline case needs to be identified and thoroughly analyzed to be used in a comparing analysis for measurements. A reviewer indicated that the program is methodical; for example, the project is gathering data from industry to baseline the current state of motor cooling before moving to modeling and experiments. The investigator also recognizes that a one-size-fits-all approach is not realistic and is focusing on the most relevant, industry-adopted technology. A reviewer stated that the project is taking a broad multi-discipline approach to find the best thermal cooling methods. This will lead to better analytical tools and methods to understand all the key factors that influence cooling from the vehicle to mechanical design and environmental.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

A reviewer stated that this is a new project (year one) and a good understanding of current cooling technologies and possibilities has been achieved. The reviewer felt that the project is addressing feedback that is solicited and being received from industry. Another reviewer noted that the thermal load data of some example PM machines have been obtained and parametric FEA thermal models were developed. The person felt that the characterization of thermal interface properties for direct oil and water cooling jacket systems

is on a good path, and that the testing of thermal material properties (e.g. for laminations) is important. Overall, the reviewer indicated that the progress towards the project goals is very good. A third reviewer noted that progress to date is not as far along as the commenter expected. There were some system models built and some simulations. A fourth reviewer hoped that faster progress will be made later, and that perhaps the scope is too broad to investigate simultaneously. Another reviewer noted that there are some good areas of research identified but so far it might be early to judge the accomplishments. More quantitative analysis and test results are needed.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

One reviewer noted that they have put together a good team of experts, with another reviewer noting that laboratories, universities and industry are all participating in this program. Another reviewer indicated that there seems to be good collaboration with the University of Wisconsin, Madison and ORNL on the project. A fourth reviewer indicated that the collaboration with the University of Wisconsin, Madison for the motor expertise is good, and that the inputs from other projects at ORNL like the benchmarking activity are beneficial for this project. The reviewer felt that the link into the Vehicle Technologies Program will ensure that overall system impacts are sufficiently considered.

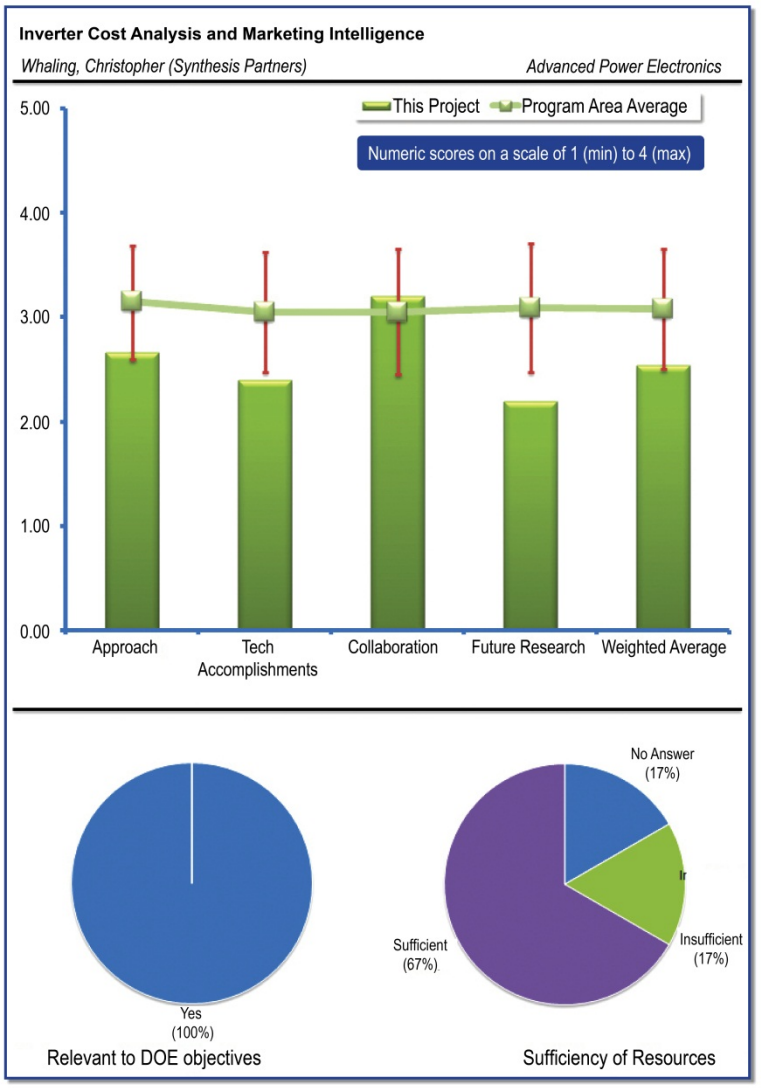
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One reviewer felt that the researchers have a clear plan for the next steps and a good understanding in which areas further work is necessary. The reviewer noted that it was mentioned in the presentation that the thermal performance improvement might lead to reduced heavy rare-earth magnet materials in PM machines, but the reviewer felt that induction machines should be investigated also as these would benefit significantly if thermal performance could be improved. Another reviewer noted that, while past work and progress is a good indicator that future work will be productive, specific plans and milestones were not clear. The reviewer encouraged more work to quantify the differences in available motor materials (e.g., difference between M19 and HF10 motor steel, comparison of stator varnish from a strength and heat rejection perspective, potting compounds to reject heat to the outer cooling jacket).The third reviewer felt that, instead of trying to look into a wide range of machine types, the commenter suggests focusing on the state of the art IPM motor and quantify what improvements can be made before moving on to other types. The fourth reviewer was not sure where the future will take this project. The reviewer felt that the project needs to be more clear about whether the goal is to look at cooling technologies or to develop thermal models.

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

All five reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

Inverter Cost Analysis and Marketing Intelligence: Whaling, Christopher (Synthesis Partners) - ape032



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

A reviewer felt that identifying cost drivers is a good means to develop a path to reduce the inverter cost. A second reviewer indicated that inverters are key components to vehicle electrification and cost/product information will help create better products. Another reviewer noted that the project discusses cost-effective approaches to vehicle electrification, and reduce vehicle reliance on fossil fuels. A fourth reviewer felt that it is worthwhile to understand the major cost drivers of power electronics to know what to attack. The reviewer indicated that the information from this project allows for a better understanding of what the issues in power electronics and electric machines are. One reviewer stated that the projection of cost and future drivers of component costs is a critical aspect of an emerging product market. The reviewer felt that without intentional and careful study to understand the limitations of rare earth element availability and cost, Li-ion battery market drivers, and TDI cost elements, it would be near impossible to successfully field profitable vehicular products in the future.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer noted that the collection of data from OEMs and Tier 1/2 Suppliers is the appropriate source of data. The reviewer felt that it will take some work to ensure that components are identified consistently to avoid confusion (e.g., one pie chart omitted thermal management and another omitted bus bars, even though both products likely included some amount of both). Another reviewer stated that projections are just that: projections. However, the reviewer felt that the subject effort is focused on the correct costs drivers for future vehicle manufacture and appear to be conducting a very thorough analysis of the critical parameters. One reviewer indicated that there seems to be two approaches depending on the study involved. One seems to be "go interview people". The other seems to be "scan a bunch of documents and look for references". The reviewer felt that neither approach seems to refine the direction of the search as information is acquired. A fourth reviewer suggests that the investigators establish more specific means to meet the goal.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

A reviewer noted that, in spite of the very large volume of data to analyze and assess the project, it is making measurable progress and appears to be on schedule. The cost breakdown of the inverter is very interesting and valuable information. A reviewer stated that the cost distribution pie chart was helpful, but each represented one sample product. The reviewer noted that the presenter acknowledged that some slices will be variable. The reviewer felt that comments regarding the effect of volume were interesting, but the reason for

the knee of the curve at 50,000 [units] is not clear and may be the opinion of one OEM or supplier. Ultimately, the reviewer felt that too few specifics were provided for a project that will conclude in August 2011. A reviewer stated that the inverter survey compares current and future cost drivers; however, the definition of categories changes between the two charts (e.g. bus bars and thermal management). The reviewer felt that the work on automated search routines does not describe a mechanism to verify the automated search results. The reviewer was curious that if the scan-search method returns a set of information, would a human search of the same documents return more or less information? The reviewer also noted that there has been no progress on the Lithium-Ion work. A reviewer felt that the differences for cost drivers for now and future inverter are not clear. The reviewer wanted to know what changes occurred and how the project plans to meet the DOE goal. The reviewer also felt that the project needs more updates on the Li-ion battery and Beyond Rare Earth Magnets segments.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

A reviewer noted that the OEM's, top tier suppliers, and all the relevant players are involved and providing input as required. The reviewer felt that anything less would not be acceptable. Another reviewer noted that the source of information includes Toyota and others, which is appropriate, but that the number of data points is unclear. The reviewer felt that it would be useful to study products that are new on the market like the Chevy Volt, the Nissan Leaf, and the Magna system for Ford. One reviewer expected the project to have more first-hand data from OEM/Supplier.

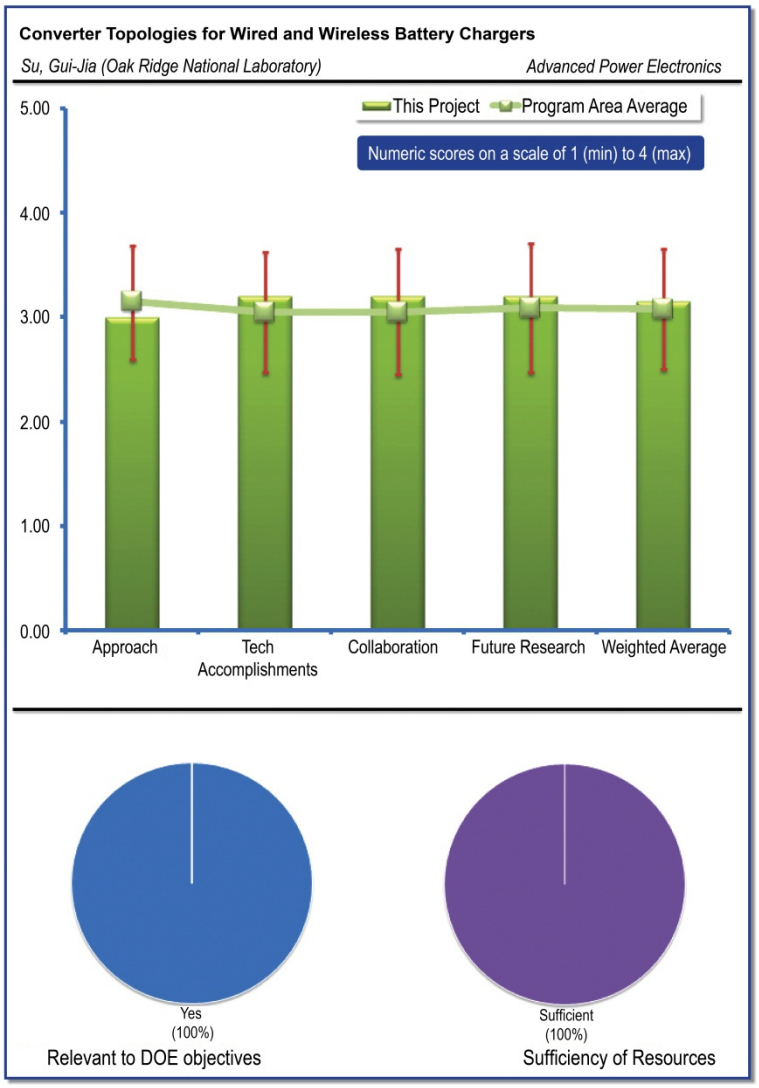
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

A reviewer stated that it was good that the final report will quantify costs rather than just the cost distribution. The reviewer felt that specific information about the underlying technologies would be useful to industry, but this reviewer understands that disclosing this would limit the input that would be received in the first place. The reviewer concluded that this limited industry input is why studying products on the market (Volt, Leaf) would be valuable, since the underlying technologies are public. The reviewer also felt that the presentation comments regarding the tendency to overdesign in the early stages of commercialization are accurate, and it will be useful to quantify this effect and offer possibilities and strategic thoughts for the future. Another reviewer noted that it was an aggressive plan to generate the cost metrics for batteries and rare earth magnets, in addition to completing the inverter analysis. The reviewer felt that all critical and necessary tasks still required completion. One reviewer noted that nothing was really specified regarding future work, and another stated that the future plan is not described in this presentation. Another reviewer remarked that discussions are ongoing.

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

Four of five reviewers felt that the resources for the project were sufficient to achieve the stated milestones in a timely fashion. One reviewer felt that the funds were insufficient.

Converter Topologies for Wired and Wireless Battery Chargers: Su, Gui-Jia (Oak Ridge National Laboratory) - ape033



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

The reviewer noted that chargers are a major cost factor for hybrid and electric vehicles. The reviewer felt that this project will explore new topologies for both wired and wireless chargers. Another reviewer noted that the project specifically addresses the need for battery charging, both wired and wireless. This reviewer felt that the technology will be needed to support HEV and EV technologies moving forward. A third reviewer noted that the project support for DOE objectives is implied but not stated. The reviewer felt that if the component cost decrease, and the overall inverter cost decreases, then this helps to enable inverters for HEV, PHEV and FCV's. A fourth reviewer noted that combining the on-board charger and other power electronics components like traction inverter is an effective way to the same system cost. Another reviewer indicated that an onboard charger adds $400 to vehicle cost and is unidirectional. The reviewer also noted that dual use propulsion inverter serving as charger and Vehicle-to-Grid (V2G) generator adds value at 90% less cost than separate charger/inverter equipment. The reviewer felt that there are important issues to address, which include previously demonstrated use of an onboard traction inverter for charging showed that it is difficult to provide galvanic isolation and cannot charge a dead battery and that a converter with high efficiency and power factor suitable for wireless charging is needed.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer stated that the approach was very good. The reviewer felt that the discussion of efficiencies was well placed and supported and that the specific introduction of charging voltage and current was well done. The reviewer also noted that the method of addressing the alignment issue for wireless charging was well discussed as it represented real-world application issues that will arise. A reviewer felt that it was a good plan to perform literature study and simulations of new concepts followed by hardware demonstration. This reviewer suggested using simulation to investigate synchronous rectification and soft switching, new topologies to reduce switch count, ac-ac-dc approach (high frequency ac link), and resonant link to improves power factor. A reviewer noted that the project has shown two new topologies that could be effective based on simulations shown. The reviewer felt that one factor that needs to be considered is cost as it looks like the wireless method will be more expensive than the wired system and the wired system is expensive already. A reviewer noted that this project was a new start, and that the problems seem to be well understood, but the designs are not complete. A reviewer noted that there is a need to address system level issue like adding EMI filter into the AC line, how to synchronize the two MCU controller to achieve charger function, etc.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

A reviewer noted that efficiencies were discussed and presented and that the simulation work of wireless charging results was shown. The reviewer chose to rate this section as a four because it seems to suggest that barriers will be overcome, and that wireless charging of this nature will proliferate. A reviewer indicated that this project has just started so accomplishments are modest at this time. The reviewer felt that the test set up showed good power transfer at 10 inches separation which the reviewer believed to be adequate. A reviewer indicated that only concepts and simulations were represented at this stage and that hardware experiments and concept verification were planned for the future. A reviewer reiterated that this project was a new start, and that the problems seem to be well understood, but the designs are not complete. A reviewer indicated that the power stage has been approved and working.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

A reviewer noted that there was adequate collaboration with partners. Another reviewer added that the level of collaboration seems well defined and each group contribution is established and outlined. A reviewer commented that the partners chosen can help to define the vehicle environment. The reviewer felt that working with knowledge sources on antenna design and inductive power transfer were excellent choices for consulting on the design. A reviewer noted that the project leader stated that project is "looking to tech team for guidance". The reviewer felt that the project might benefit from more coordination and collaborations to establish V2G requirements.

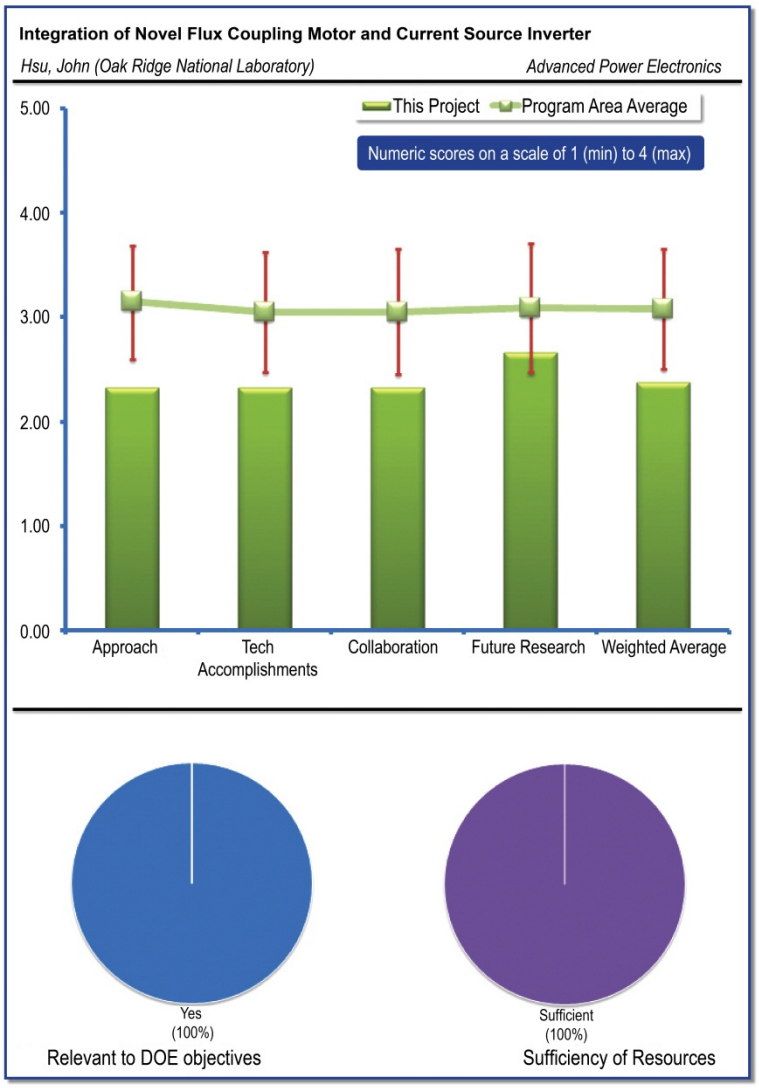
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

A reviewer noted that the plan is clear to achieve the final objectives. Another reviewer commented that there was an excellent outline of the future goals. The reviewer did want to see some quantification, if possible, for cost, performance, and manufacturing goals and targets, etc. The third reviewer noted that design(s) is/are still being formulated, and it has not been shown how the barriers, like isolated integrated charger, will be addressed. The reviewer felt that the barriers appeared to be taken into account in the presentation. Another reviewer felt that this work is very important in that it could lead to another method of vehicle charging. However, at some point in the future this method will compete with direct charging via Society of Automotive Engineers (SAE) J1772 standards and the reviewer thinks that most OEMs will not want to have a dual charging system unless there is an advantage. The reviewer hopes that the researchers look at some of the practical implementation issues such as EMI and safety concerns. The fifth reviewer noted that a hardware demonstration of dual use propulsion inverter with galvanic isolation and dead battery charging would be valuable and that it was not clearly defined in the future work what V2G functions will be included in the study be simulating.

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

All five reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

Integration of Novel Flux Coupling Motor and Current Source Inverter: Hsu, John (Oak Ridge National Laboratory) - ape034



Reviewer Sample Size

This project had a total of three reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

A reviewer stated that the project supports the goal of improving the traction system. Another reviewer noted that the program attempts to find synergies between a novel inverter and motor by using a single coil assembly to satisfy both the inverter inductor and motor excitation needs. The reviewer believes that a successful implementation would further vehicle electrification.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

Another reviewer felt that the approach is an excellent and novel idea; however, it has very limited application. The reviewer noted that it combines the unique current source Quasi Z source inverter developed by Dr. Su at ORNL and the novel flux coupling motor by Dr. Hsu. The reviewer noted that both were very experimental at the time of the review. It was unclear to one reviewer that the inverter inductor and motor excitation needs may be satisfied with a single coil assembly. The reviewer felt that the requirements seem too different; more detail in the slides would have been helpful to show that the approach has merit and that it is difficult to evaluate the approach without these details.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

A reviewer noted that, at the time of the review, the project is just getting started so there are just feasibility work results. Another reviewer noted that the program has only been going for about 6 months, but this is enough time to describe the parameters of the inductor/coil assembly and how it meets the needs of both the inverter and the motor. The reviewer remarked that it would be useful to describe how the AC blocking coil will be placed in the motor (without negating the inductance used for the inverter) and how the secondary coil will be integrated for additional flux production.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

One reviewer noted that no collaboration information was provided. Another reviewer noted that it was their belief that this work is mostly internal to ORNL.

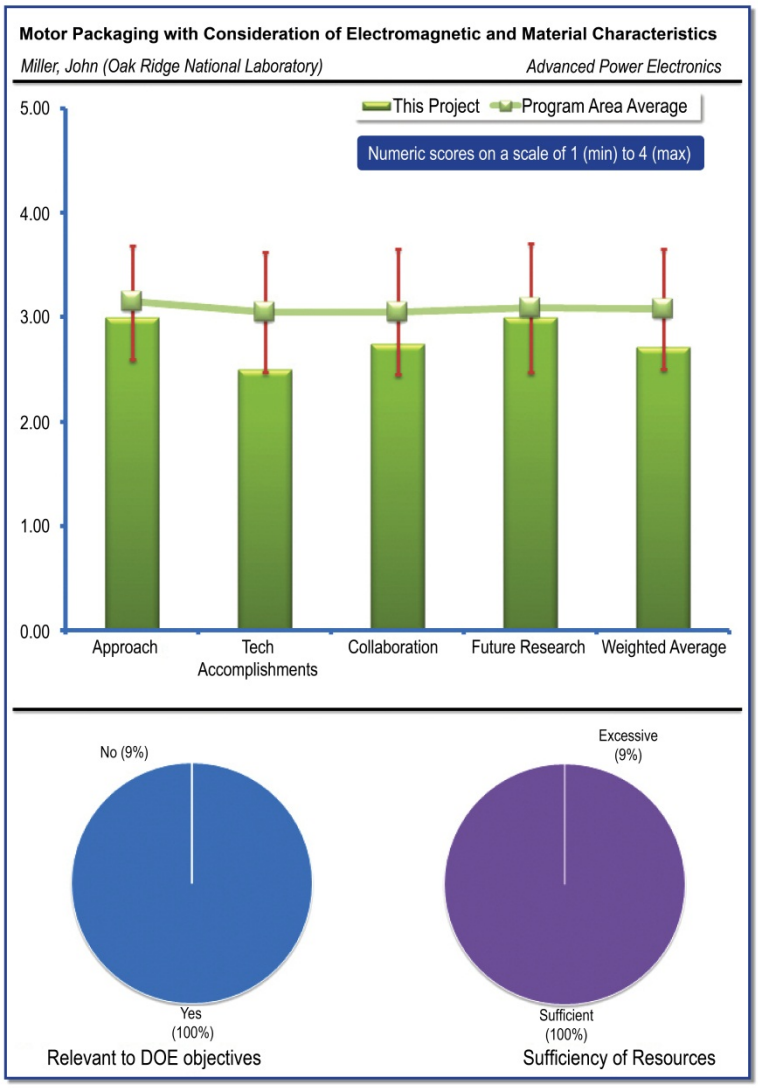
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

A reviewer indicated that the goals for the remainder of FY11 are vague. A coil with sufficient leakage inductance for the CSI will likely be possible. The reviewer was unclear about how the AC flux blocking function is quantified. The reviewer was concerned that the program may be moved forward with an insufficient go/no-go standard and then struggle for the next year or two. The reviewer indicated that programs led by intelligent people may fail if too many novel features are stacked on top of one another, and this is what the program looks like. A reviewer noted that the future work looks good for the scope of the project. However, the scope of the system is extremely limited and not generally applicable.

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

All three reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

Motor Packaging with Consideration of Electromagnetic and Material Characteristics: Miller, John (Oak Ridge National Laboratory) - ape035



Reviewer Sample Size

This project had a total of four reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

A reviewer stated that motors are a key component of any traction system and this work will help improve motor efficiency and cost. The reviewer felt that this was important to the growth of electric and hybrid vehicles. A reviewer noted that the project is targeting increasing the efficiency of traction motors as well as increasing the continuous power rating of these motors. The final reviewer indicated that improved propulsion motor efficiency and power support increased vehicle electrification.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer noted that trying to understand the various loss components as well as the various torque components is a good starting point. The reviewer remarked that the next step of evaluating the motor's performance using the proposed materials properties will help quantify the potential benefits. A reviewer indicated that the PI is looking at many key factors of motor design including winding methods, laminations, and rotor losses. This approach is analytical in the beginning and empirical in the end. In addition the PI is looking at novel lamination rolling methods to lower stator losses. Another reviewer indicated that much of the work that is proposed appears to be learning about issues that are already known in industry: motor windings, magnet leakage flux, air-gap flux shaping, lamination steel performance. The reviewer feels that it will be interesting to share these design methodology insights, and perhaps investigate alternatives, but thinks that this project an odd fit for a national laboratory. Since the work has just begun, the reviewer wondered whether or not the work will produce surprising results.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

A reviewer indicated that the project just started in 2010 so there are not many results. Another reviewer noted that the project started in FY11. The reviewer stated that the work done so far is mainly finite element analysis simulations that are fairly straightforward and well known. The reviewer commented that more rigorous analysis and simulations based on expected materials properties should be performed as soon as possible. A reviewer noted that as a new program, little progress has been made and it remains to be seen where it leads. The reviewer feels that better high frequency and heat transfer materials are needed, so this work (bullet #3 of the FY11 Future Work) should be a focus item. The reviewer also noted that it is important to increase the efficiency in the light-load, mid-to-

high-speed region of operation and not so important to increase the high torque efficiency. In addition, the reviewer indicated that efficiency increases are more important than continuous power increases in automotive applications.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

A reviewer remarked that there is an excellent team assembled for this project. Another reviewer noted that collaboration with NREL and ORNL's Material Science division are appropriate. The reviewer stated that they have wondered for some time why the ORNL Material Science team was not engaged in these programs. The reviewer also encouraged industry involvement. The third reviewer stated that the work done so far is mainly within the machines group within ORNL. The reviewer observed that it remains to be seen how the collaboration with the materials group within ORNL will evolve as well as the collaboration with NREL.

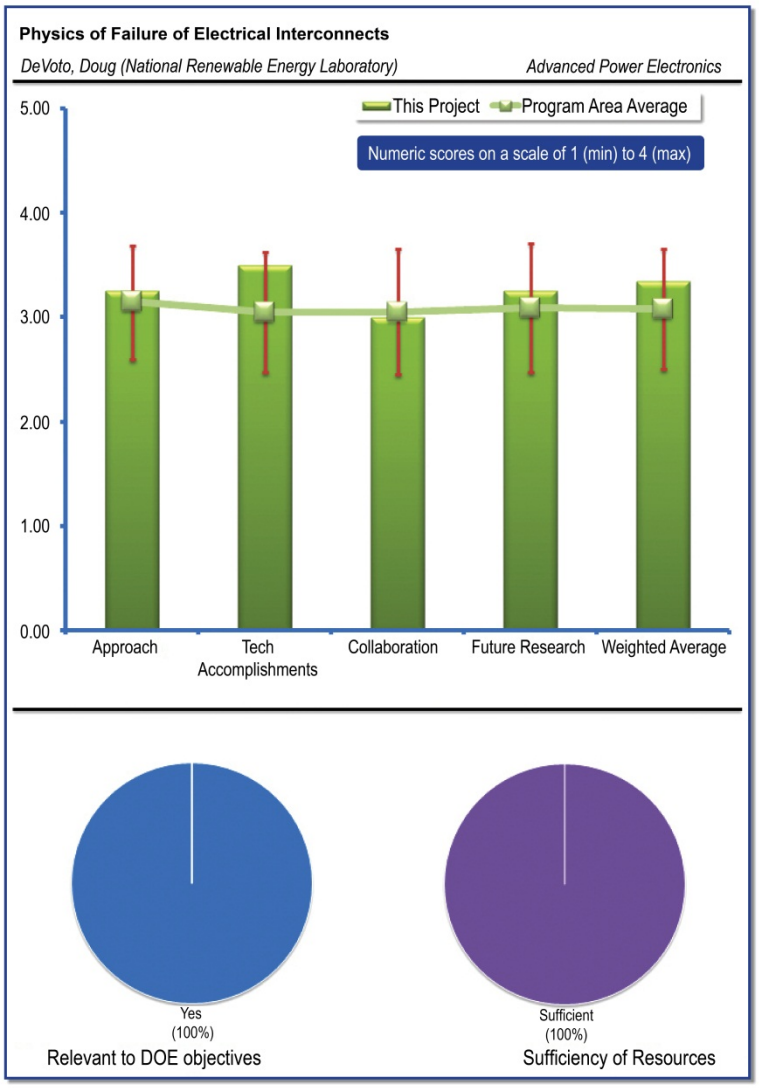
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One reviewer expressed that this project is on the right track and the proposed work is meaningful and practical. The second reviewer noted that future work with a focus on light-load efficiency improvement is encouraged. The reviewer felt that this may lead to innovative ideas, or toward ideas that are already known in industry and felt that it would be interesting to look at this work next year at the merit review. Another reviewer stated that if the analysis and simulations based on expected materials properties shows promising results in terms of motor's performance, then the proposed future work of developing these materials and eventually using them to build and test a motor makes sense. If the analysis does not show promising results then it is not recommended to proceed with the materials development.

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

All four reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

Physics of Failure of Electrical Interconnects: DeVoto, Doug (National Renewable Energy Laboratory) – ape036



Reviewer Sample Size

This project had a total of four reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

One reviewer noted that the ribbon bonding process has the potential of increasing the reliability and current capabilities of electrical interconnects. With this, the design of advanced power electronics would be enabled which supports the DOE objectives. Another reviewer indicated that this project is a key element of understanding what is necessary to have a reliable and cost effective power module. The third reviewer stated that for electric drive vehicles to be successful in the market, they must be as reliable (if not more reliable) than a conventional vehicle. The reviewer felt that the project addresses one of the weak points of today's electronics.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer felt that the approach is logical and straightforward. Another reviewer stated that, in contrast to many other projects, this project aims to investigate a very specific topic. The reviewer remarked that the approach is good because it will ensure that the focus is not lost in a multitude of goals. The reviewer also noted that different geometries and materials for ribbon bonds will be developed and tested. Moreover, simulation models for electrical interconnects will be developed or improved. A third reviewer indicated that the principal investigator will need to keep this well-coordinated with the physics of failure activity on power modules/inverters.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer stated that the accomplishments to date are fine. Another reviewer noted that the project is still in an early phase but the plan which has been set in place is good. The reviewer felt that the selection of industry partners is important and will add value to the project and the reliability testing is initiated and will lead to a better understanding of the new bonding technique.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

One reviewer indicated that the choice of collaboration partners is good, especially the fact that the input from industry is actively pursued which is often not the case in research projects. Another reviewer wanted to know how the data are getting to industry. The reviewer felt that unless the data are used to solve problems they are useless.

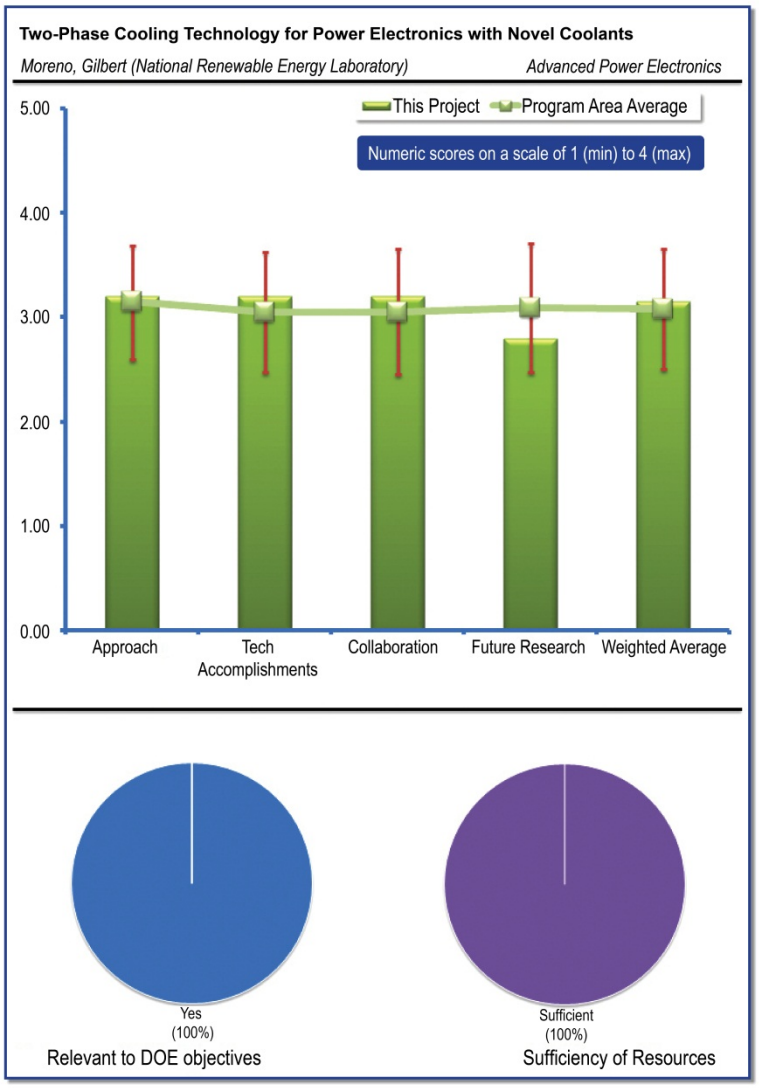
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

A reviewer stated that the researchers have set up a clear and detailed plan how to proceed with the testing. The reviewer commented that it would be interesting if more details about the modeling activity will be provided in the future. Another reviewer felt that collaboration with other DOE projects will provide a very powerful tool to solve this issue.

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

All four reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

Two-Phase Cooling Technology for Power Electronics with Novel Coolants: Moreno, Gilbert (National Renewable Energy Laboratory) - ape037



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

A reviewer stated that a two phase cooling concept has the potential to increase the power density of power electronics and thus does support the DOE objectives. Another reviewer agreed, stating that the ability to remove heat from the unit is fundamental to creating a cost effective and reliable unit. A third reviewer noted that better thermal performance helps to reduce the cost of power electronics helping to enable the market for power electronic devices. One reviewer remarked that this project doesn't address the fundamental cost issue, but that the project may support DOE objectives in the long term.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer stated that in this project the higher heat transfer capabilities of two-phase cooling systems will be investigated including surface enhancements and other measures. The reviewer felt that the approach to performing this work is good and that collaboration with industry partners regarding the refrigerant and surface treatment chemistry aspects is valuable. One reviewer indicated that the project needs to demonstrate how this approach will lead to meeting [FY/CY]2015 DOE APEEM cost [estimates/requirements]. Another reviewer noted that the barriers to effective two-phase cooling are being addressed in terms of cooling medium and various approaches. The reviewer felt that the strengths and weaknesses of these materials need to be investigated from how they would be used and/or implemented in a vehicle. As an example from the reviewer, a submerged cooling approach with a fluid that boils requires a space above the level of the fluid for the vapor to rise and condense. Further, this reviewer continued, if this space is not properly sized then under some operating conditions the hardware may become exposed and fail. Additionally, the method by which signal interfaces are supported also needs to be addressed. The reviewer felt that none of these issues were insurmountable but would need to be addressed to get support from a manufacturer. A reviewer noted that this project is a new start. The reviewer was interested to know how the principal investigator planned to convince the commercial industry that the system that uses this approach is reliable. The reviewer wanted to know if it would be possible to provide a straw man list of tests and their required results to convince industry this could be a reliable system. The reviewer felt that industry would be able to add to the list of tests and results needed to determine reliability. Another reviewer wanted to compare what would happen if the 3M micro porous coating was applied to the Lexus part and applied it thru TIM to a cold rail to what would happen without the 3M coating.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

A reviewer noted that the progress that was shown indicates that the performance of these mediums is excellent. Another reviewer stated that the project is in an early stage but the researchers started immediately with tests of immersion boiling. The reviewer noted that it was proven that immersion boiling with enhanced surfaces decreases the thermal resistance significantly which is a somewhat expected result. The reviewer felt that what is missing so far is the evaluation of the overall system impact of these kinds of cooling technologies. It has to be evaluated early on what the effects are on sealing, contamination issues and especially costs of the system. The reviewer noted that it was mentioned in the presentation that this research is planned for FY 13, but the reviewer felt that this was too late for this activity to occur in the project timeline. A third reviewer noted that this project is a new start; the reviewer felt that the project had a very good thermal performance possible but that there is a need to address system issues as well as legacy issues. The reviewer wanted to know what went wrong with Continental's red box in the GM application and what would GM need to convince themselves this could be a viable approach.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

A reviewer noted that the project has the right partners, but they need to help by providing input on how to define the requirements for the system. Another reviewer stated that the collaboration with the industry in terms of material science is very good. The reviewer felt that additional input and support is needed from power electronics suppliers for the evaluation of the overall system impacts. A third reviewer felt that potential suppliers of power electronics need to be added to the team fairly soon to assist in answering some of the implementation issues that may require a change in the approach.

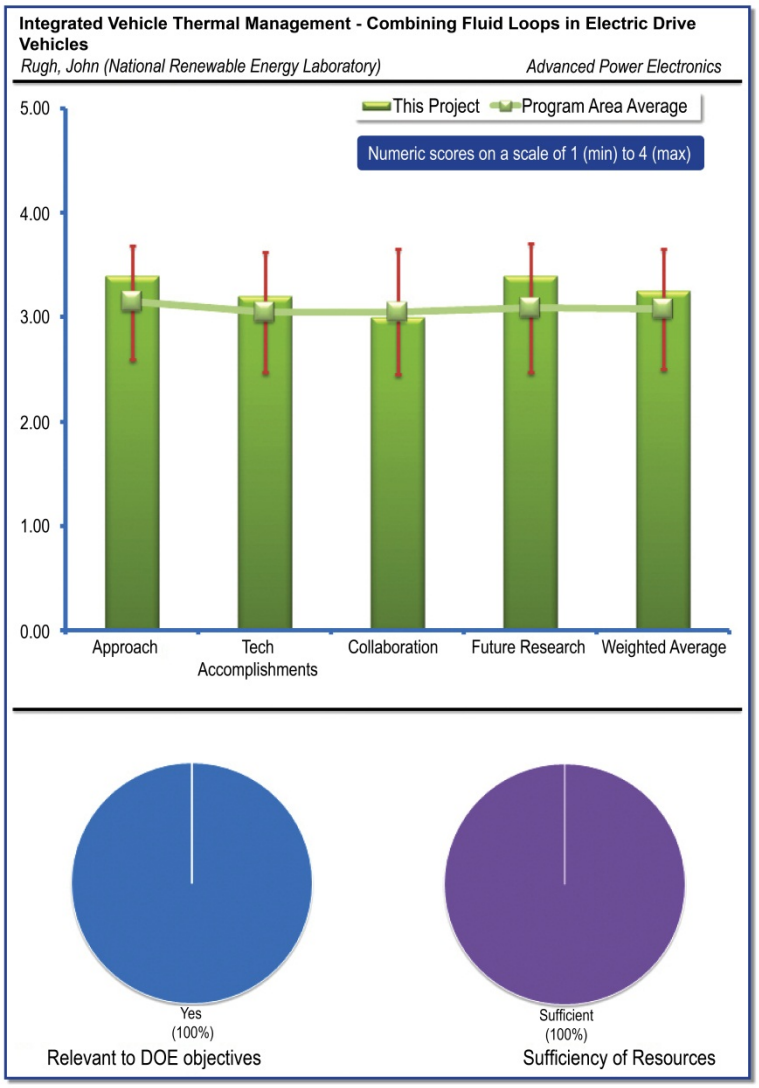
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One reviewer noted that plans were reasonable and addressed the issues that had been seen to date. Another reviewer stated that the future work plan regarding the investigation of the two-phase cooling concept itself is good. The reviewer felt that what has to be added as soon as possible to the planned work is an investigation of the applicability of the novel cooling technique in real-world power electronics. The third reviewer noted that the scope may be increasing as the definition of the system requirements develop. A fourth reviewer indicated extreme concern about the direction of this project and its ability to provide something useful, but believed the technical work was good.

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

All five reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

Integrated Vehicle Thermal Management – Combining Fluid Loops in Electric Drive Vehicles: Rugh, John (National Renewable Energy Laboratory) - ape038



Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

One reviewer stated that the combination of cooling systems for different subsystems in an electric vehicle might lead to cost reductions and system simplification with increased reliability. The reviewer felt that this supports the DOE objectives. A second reviewer felt that this project could be very helpful in improving cost and reliability by simplifying thermal system on the vehicle. Another reviewer indicated that the project's ability to support DOE objectives was not directly stated but that utilizing existing cooling systems within the vehicle can lower the cost of automotive power electronics and help to enable the market. A fourth reviewer noted that the project has the potential to reduce the cost of the vehicle.

Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer stated that an extensive effort is planned to model the thermal characteristics of all subsystems in an electric vehicle. The reviewer noted that it has to be ensured that all subsystems are modeled accurately so that the benefits of combining cooling loops can be evaluated. The reviewer felt that the involvement of industry experts is crucial for this part of the project. Another reviewer noted that this project is a new start. The reviewer felt that reuse of existing cooling system models is a good approach as it helps to minimize time and allows the project to concentrate on the system modifications required of a combined cooling approach. A third reviewer agreed that the number of thermal systems in some vehicles is excessive. The reviewer felt that the desire to reduce them is noble but the reviewer was not sure that this project can address all of the causes as some are based on the internal structure of the OEM. The reviewer stated that sometimes cross-functional teams don't play well together. The reviewer felt that if this project can show that it is possible to address the cooling needs of the various systems with common cooling loops then that will be a significant aid in getting the teams to cooperate. One reviewer felt that there was a need for more specifics in the objectives.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

One reviewer remarked that the approach is good. Another reviewer stated that the progress is very good considering that the project was started in FY2011. The reviewer noted that a process for the thermal modeling of cooling loops was set up and models for several subsystems were implemented. The reviewer felt that the assumptions for the modeling of the subsystems should be explained in more detail. The reviewer noted that, generally, OEMs have reasons for choosing different cooling loop temperatures for different

subsystems in electric vehicles because this leads to optimal designs for the subsystems. The reviewer felt that this has to be accurately reflected in the models, so that the outcome of the overall system model also accurate. A third reviewer indicated that progress on the technical piece is very good. The reviewer wanted to know if the FAST tool had been verified and wanted to know if it predicted reasonable values.

QUESTION 4: WHAT IS YOUR ASSESSMENT OF THE LEVEL OF COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS?

One reviewer stated that the collaboration with Visteon is probably not sufficient for the accurate modeling of all subsystems, especially for the electric drive system components. The reviewer remarked that additional OEM and suppliers have to get involved. The reviewer also felt that the collaboration between the VTP members is important. Another reviewer felt that the idea of getting strong support from a single OEM is good, but may be difficult. The reviewer noted that the combined cooling approach encroaches on many subsystems that today may not have a common goal. The reviewer expressed hope that the project can pull them together. A third reviewer noted that the project probably needs more cooperation from OEMs especially the different teams within an OEM but that this might also cause a delay in the project. The fourth reviewer suggested that the project work with only one OEM.

QUESTION 5: HAS THE PROJECT 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?

A reviewer felt that the approach was well defined. Another reviewer indicated that the project plans were great but that it was unclear how the project results will get implemented in the OEMs. A third reviewer felt that building a prototype system after the extensive modeling effort is the right approach; however, the reviewer thought that it was unclear how building a prototype system will be accomplished with the allocated budget since the reviewer felt that it would be an expensive prototype system. The reviewer suggested that additional comments on the prototype system, particularly the costs, could be included in the next review. The reviewer also felt that, besides the costs of building a prototype, the system cost impact in a production has to be evaluated (i.e. how are the subsystem costs influenced by the combination of cooling loops).

QUESTION 6: HOW SUFFICIENT ARE THE RESOURCES FOR THE PROJECT TO ACHIEVE THE STATED MILESTONES IN A TIMELY FASHION?

All five reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.

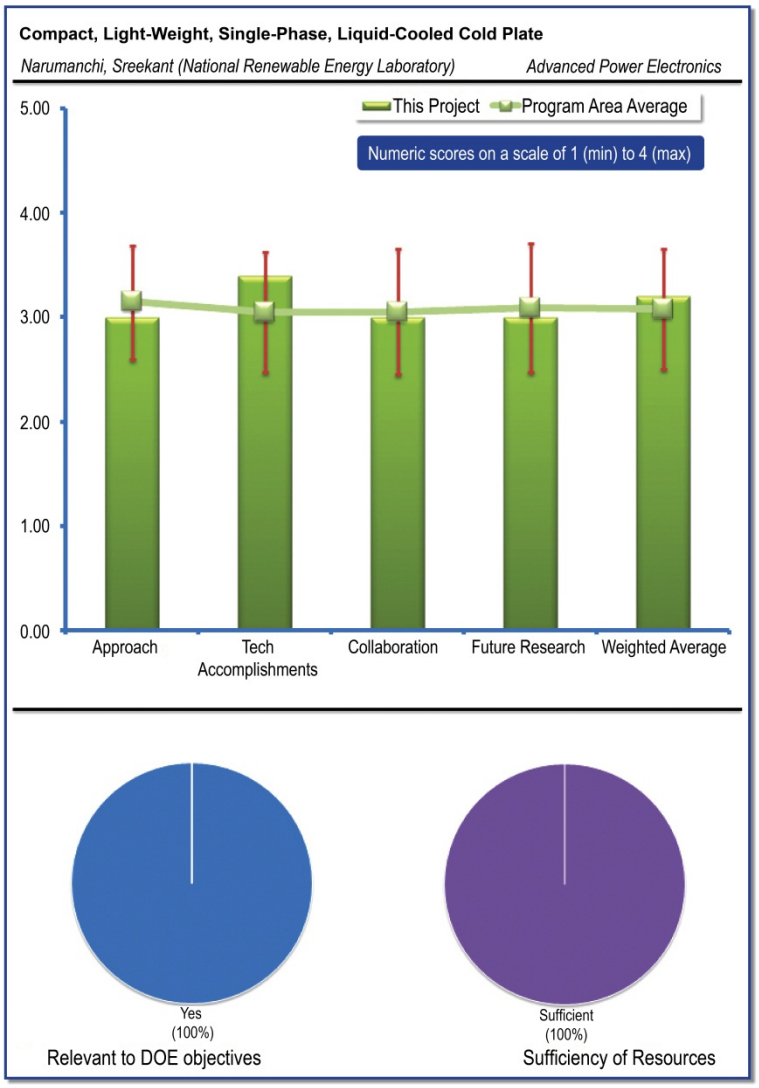
Compact, Light-Weight, Single-Phase, Liquid-Cooled Cold Plate: Narumanchi, Sreekant (National Renewable Energy Laboratory) - ape039

Reviewer Sample Size

This project had a total of five reviewers.

Question 1: Does this project support the overall DOE objectives? Why or why not?

A reviewer commented that the effective management of waste heat in emerging vehicle technology is fundamental to the successful deployment of cost competitive products with power density, volume, total weight, and efficiency metrics that yield measurable fuel displacement. The subject project is focused on addressing the key heat transfer paradigm for the traction drive inverter cooling heat exchanger. In order to achieve the required PCU efficiency, and thus energy savings, high heat transfer coefficient cooling is absolutely necessary. This project focuses on an evaluation of a potentially game-changing cooling technology which could enable the attainment of PCU power density metrics and improve electronic device reliability by reducing junction temperatures. Another reviewer noted that improving heat rejection from electronic components can extend the operating efficiency and range of inverters and converters. This reviewer further observed that advanced cooling is compatible with existing cooling systems used for power electronics on vehicles.



Question 2: What is your assessment of the approach to performing the work? To what degree are technical barriers addressed? Is the project well-designed, feasible, and integrated with other efforts?

A reviewer felt that the potential heat transfer coefficient attainable using the single phase impingement jet heat exchanger is very attractive. The reviewer noted that much work has historically been accomplished on spray type cooling, surface modification, and heat transfer and that the problems have always been one of reliability, complexity, and fluidic contamination and clogging. These critical issues required focused attention to either mitigate or eliminate prior to reliable operation in vehicular platforms. In addition, the reviewer felt that it is common to conduct heat transfer research using only steady state/equilibrium analysis, i.e. First Law energy balance, but that it is increasingly important to consider the dynamic Second Law effects as power density is increased, which necessarily reduces heat capacity leaving components susceptible to large temperature excursions. A reviewer noted that the project describes a plastic heat exchanger, but the implementation is somewhat different. Although there seems to be a plastic manifold, the heat exchange actually takes place on an aluminum surface that is conditioned. The reviewer felt that that does not detract from the importance of the work but that the project is not described correctly.

Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.

A reviewer stated that the accomplishments were a good start for this stage of the project. Another reviewer indicated that the project appears to be progressing on schedule with impressive heat transfer coefficients demonstrated with the impingement jets. If carefully

considered, this type of technology can have significant impact on vehicle electronics reliability through controlled junction temperature excursions.

Question 4: What is your assessment of the level of collaboration and coordination with other institutions?

One reviewer noted that the collaborations with HEV and PEV drive manufacturers and electronics cooling expertise was very good. The reviewer's only recommendation was to collect power module manufacturer input on device response and impacts to module performance as a result of the cooling technology changes to base plate boundary conditions.

Question 5: Has the project 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?

One reviewer felt that the plan to complete the subject study was very good and well organized. The reviewer made a point to refer the project partners back to prior comments recommending non-equilibrium thermodynamic analysis here. Another reviewer felt that it is good to consider the long term effects of the jet on base-plate finish. The project would be enhanced by defining pass/fail criteria for the effects. The third reviewer indicated that the project could be further enhanced by evaluating the advisability of multiple jets per surface. The reviewer suggested that the project explicitly determine if multiple jets help and how much separation should exist between multiple jets.

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

All five reviewers felt that the funding resources were sufficient to achieve the stated milestones in a timely fashion.